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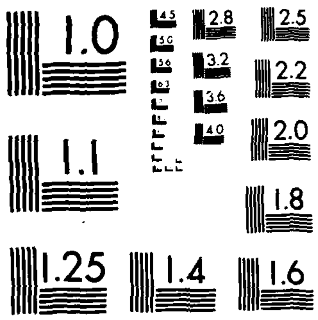

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California Earthquake Residual Transportation Capability Study

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December 1983
Final Report

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16. Abstract

This report addresses the ability of transportation facilities in California to survive four postulated earthquakes that are based on historical events. The survival of highways, railroads, ports, airports, and pipelines is investigated following individual earthquakes along the San Andreas and Hayward faults in Northern California and the San Andreas and Newport-Inglewood faults in Southern California.

Each of the four example earthquakes would cause extensive damage to transportation routes in California; however, most damage would be of a local nature, affecting either the San Francisco Bay Area or the Los Angeles area. Major intercity routes would survive intact outside the damaged area. The report identifies critical routes and highlights the need for emergency planning to focus repairs on these routes.

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CALIFORNIA EARTHQUAKE RESIDUAL TRANSPORTATION CAPABILITY STUDY

By Paul S. Jones

Prepared for:

Transportation Systems Center
U.S. Department of Transportation
Cambridge, MA 02142

SYSTAN, Inc.
Los Altos, CA 94022

PREFACE

This report presents the results of an investigation into post-earthquake residual transportation capability in California. The work considered four major earthquake scenarios and highway, railway, waterway, air and pipeline transportation. Attention is focused on surviving intercity transportation rather than on problems of post earthquake access.

The work was sponsored by the Office of Emergency Transportation of the U.S. Department of Transportation. The work was monitored by the Intermodal Studies Division of the Transportation Systems Center. Dr. Lawrence M. Jordan served as the Contracting Office's Technical Director.

SYSTAN is indebted to Dr. Jordan for his support and guidance throughout the project, and to the following persons for their unique contributions:

- Dr. Jack F. Evernden of the U.S. Geological Survey who prepared estimates of earthquake intensities for critical transportation facilities;
- Dr. Karl V. Steinbrugge who provided valuable suggestions on methods of damage assessment and identified many useful documents;
- Dr. James F. Davis, Geologist of the State of California, who generously shared the results of his regional earthquake studies;
- Mr. James H. Gates, of the California Department of Transportation (Caltrans), who provided a list of highway bridges judged to be structurally deficient; and
- Mr. Eldon D. Klein, of Caltrans, who provided location and structural data for structurally deficient bridges.

SYSTAN and the author are solely responsible for the analytical methods used and the conclusions drawn.

EXECUTIVE SUMMARY

Earthquakes threaten life and property in many parts of the United States. The direct effects of a major earthquake can kill persons in many ways--some victims would be in structures that collapse; others may be killed by falling debris; still others may be victims of ruptured dams or land slides. Additional lives can be lost if injuries are not promptly treated and if survivors are denied water, food and other essentials for life.

The support of a surviving population depends heavily on transportation--highways, railroads, airports, sea ports and pipe-lines. If adequate transportation facilities survive a major earthquake, there is a good likelihood that persons not killed by direct earthquake effects will survive.

This report addresses the ability of transportation facilities in California to survive four postulated earthquakes that are based on historical events. These are:

1. An 8.3 Richter Scale magnitude earthquake on the San Andreas Fault, near San Francisco, similar to the 1906 earthquake;

2. A 7.5 Richter Scale magnitude earthquake on the Hayward Fault similar to but greater than the 1868 earthquake;

3. An 8.3 Richter Scale magnitude earthquake on the San Andreas Fault, near Los Angeles, similar to the 1857 earthquake; and

4. A 7.5 Richter Scale magnitude earthquake on the Newport-Inglewood Fault similar to but greater than the 1933 Long Beach earthquake.

These four examples have been selected because they represent maximum potential for destruction in urban areas and because they are centered on faults that could experience sufficient slippage to generate earthquakes of the magnitudes selected.

North San Andreas Fault Earthquake

An 8.3 magnitude earthquake on the north end of the San Andreas Fault would be accompanied by 400 km of surface faulting. Extensive damage would occur along the fault and in areas of poor soil that lie within about 50 km of the fault. The areas subject to most severe damage would be between Hollister and Petaluma. Heavy damage would also occur along the Pacific coast, north of San Francisco.

Transportation damage would be extensive. Highway access to the San Francisco Bay Area would be limited to a few routes. Parts of Marin County and the coast north and south of San Francisco are likely to be isolated. Rail service would be stopped at Fairfax, Concord, Niles Canyon and the Pajaro River effectively isolating the Bay Area. Airports and sea ports would fare little better with surviving facilities located at Fairfax, the Carquinez Strait and Suisun Bay.

With limited transportation facilities available after an earthquake, the problems of supply and evacuation would be large. Cargoes could be brought to Fairfax by air; Crockett/Martinez by water; Livermore and Pittsburgh by rail. From these points all distribution would have to be by highway, using surviving arteries where they exist, but depending heavily on emergency routes over surface streets.

Post earthquake transportation repairs should focus on establishing transportation routes to the Bay Area. Highway repairs should concentrate on north south routes to Marin County, the San Francisco Peninsula and the East Bay. Rail repairs should focus on opening Niles Canyon and a route from Martinez to Richmond. Marine terminal repairs should focus on building temporary facilities with ground access in San Francisco and the East Bay.

Hayward Fault Earthquake

A 7.5 magnitude earthquake on the Hayward Fault would produce San Francisco Bay Area damage similar to the North San Andreas

Fault earthquake. However, because the Hayward fault is shorter, damage would be restricted to the Bay Area, between Napa and Watsonville.

Post-earthquake transportation in and about the Bay Area is likely to be extremely limited. With some repair work, limited highway transportation could be available to the San Francisco Peninsula, San Jose, Contra Costa County and northern Marin County. Other areas, particularly the East Bay, would be accessible only by water and then only through temporary port facilities. Railroad service would terminate east of the Oakland hills, south of San Jose and at Fairfield. Air transportation would be similarly constrained. Limited emergency supplies could be moved by military aircraft or helicopters to several Bay Area points; but large volume traffic would need to be routed to Travis A.F.B. for forwarding by highway or water.

Post-earthquake transportation would benefit immeasurably from the construction and operation of a number of emergency intermodal terminals. Rail/highway terminals at Fairfield and Morgan Hill could be used to forward emergency material to Marin County and the San Francisco Peninsula. Rail/water and air/water terminals on the Sacramento River would support water movement to the San Francisco Embarcadero and to the East Bay.

South San Andreas Fault

An 8.3 magnitude earthquake on the South San Andreas Fault would cause extensive damage between San Luis Obispo and San Bernardino. Surface faulting would rupture most transportation routes east of the Los Angeles Basin. Actual damage to Los Angeles would be slight because the fault is about 50 km distant from Los Angeles.

Intercity highways that reach Southern California from the north and east would be seriously damaged near the fault and where

they cross alluvial. The only post-earthquake highway access would be via San Diego and routes that pass south of the area of surface faulting. Emergency highway routes could be quickly established to serve most, if not all, of the Los Angeles area. These routes would depend on Interstate Highways 10 and 8 from the east. Detours would need to be established around San Bernardino and other areas of local damage. When emergency repairs are complete, the highway network could carry about 40 percent of the pre-earthquake capacity.

Rail service would be effectively denied to the Los Angeles area. Some intermodal shipments could be transferred to highway carriers near Beaumont or Palm Springs. This activity would add to the burden of the damaged highway network. At best the rail network could support five percent of its pre-earthquake traffic.

Pipeline networks are likely to be damaged or ruptured where they cross the fault. Limited alternative routes are available via the San Gorgonia Pass. Surviving pipelines could supply about one fourth of the pre-earthquake natural gas; underground storage could supply more.

The petroleum industry would survive essentially intact. Major refineries would likely shut down for inspection, but they could probably reopen in a few days. Central Valley sources of crude petroleum would be cut off by pipeline ruptures at the fault, but refineries could be supplied by water. Damage to product pipelines may affect Southern Nevada and Arizona; but highway distribution will be possible.

Airports and marine terminals are expected to survive almost intact. These could be used for evacuation and for supplying emergency supplies.

Newport-Inglewood Fault

A 7.5 magnitude earthquake on the Newport-Inglewood Fault would produce heavy damage throughout the Los Angeles Basin. Surface faulting is likely to extend from Culver City through

Gardenia, Signal Hill and Huntington Beach to Newport Beach. The damaged area would extend from the San Fernando Valley to Oceanside.

Because of the location of the fault, heavy damage is likely to be inflicted on major airports and on major port facilities. In sharp contrast, intercity highway, railway and pipeline routes would remain intact, with some detours necessary. Highways would be most seriously affected with through routes on I5 and U.S. 101 disrupted. Nonetheless, one third of the pre-earthquake intercity highway capacity would remain.

Emergency transportation services to earthquake victims would need to exploit modal combinations. Only highway emergency routes could be expected to reach most victims. These would use surface streets, avoiding areas of heavy debris and fallen bridges. Air service would be available at Ontario or the Air Force Base near San Bernardino. Ocean service could come from San Diego via highway. Survivors in the San Fernando Valley would be supplied by distribution trucks that secure freight from intercity motor carriers and railroads in the Oxnard area. Limited air service would be available at Ventura County airport and marine service would be available at Port Hueneme.

Natural gas trunk pipelines would survive intact. However, distribution to the damaged area would be interrupted by breaks in feeder lines. Gas sources to coastal power plants would be interrupted by pipeline breaks at or near the fault.

The survival of petroleum pipelines and product pipelines would be of little immediate consequence because of damage to the major refineries and the ports of Los Angeles and Long Beach. Nonetheless petroleum pipeline breaks could pose fire hazards that would be of great concern.

<u>Summary</u>

Each of the four example earthquakes would cause extensive damage to transportation routes in California; however most damage

would be of a local nature, affecting either the San Francisco Bay Area or the Los Angeles area. Major intercity routes would survive intact outside the damaged area.

Earthquake damage is likely to isolate large pockets of survivors. However, if emergency repairs are focused on critical routes, emergency services can be available to almost all survivors within a few days. This finding points to a critical need for organizing to meet earthquake emergencies. Construction equipment must be concentrated on a few carefully selected emergency routes. Transportation must be limited to critical supplies. Decisions about evacuation should reflect transportation capabilities.

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LIST OF EXHIBITS (cont'd)

I. INTRODUCTION

Throughout its history, and that of its predessor agencies, the Office of Emergency Transportation (OET), U.S. Department of Transportation (DOT) has been concerned with planning for massive emergencies. Initially, attention was focused on nuclear attacks. More recently, OET/DOT has directed some of its attention to contingency planning for large scale natural disasters such as hurricanes, floods, droughts, volcanic eruptions and earthquakes. Of these, earthquakes are perhaps the most feared because they take place without warning; they can be accompanied by massive destruction, and they can bring sudden death or injury to hundreds of thousands of people.

Few natural phenomena can match an earthquake for sheer destructive power. Earthquakes have leveled cities, dammed rivers, made lakes out of forests and sent waves of immense energy (tsunami) across oceans to bring destruction to all of the shores that they reach. Few sensations are more frightening than the sudden, violent shaking of the earth underfoot. When this motion is amplified by the natural periodic movement of a tall building it can be terrifying.

Earthquakes can bring modern urban areas to their knees. Even though only a few buildings are actually destroyed, electric power can be lost to large areas, water mains can be severed, gas lines broken, sewer lines ruptured and other vital services lost at least temporarily. If damage is confined to a small area, as it was in the 1971 San Fernando earthquake, then fire, police and other emergency services can cope with the major problems. However, a massive earthquake that causes extensive damage throughout a large urban area can present problems on a scale that is beyond the capabilities of local emergency services. Contingency plans

are needed to organize emergency services so that they can marshall resources and apply them where needed to save lives and to support survivors until emergency repairs can be completed and rebuilding can be initiated.

This report is concerned with transportation facilities and with the impact that a major earthquake can have on the ability to transport people and goods to, from and about areas that are heavily damaged by earthquakes. Two topics are of primary concern:

1. The damage that a major earthquake is likely to inflict on transportation facilities; and

2. The capability of the surviving transportation facilities to support the movement of people and goods.

The earthquakes of interest are those which are large enough to cause widespread damage and disruption to transportation and other services. The geographical setting is the State of California, a state that has suffered more large earthquakes than any other state in the Union.

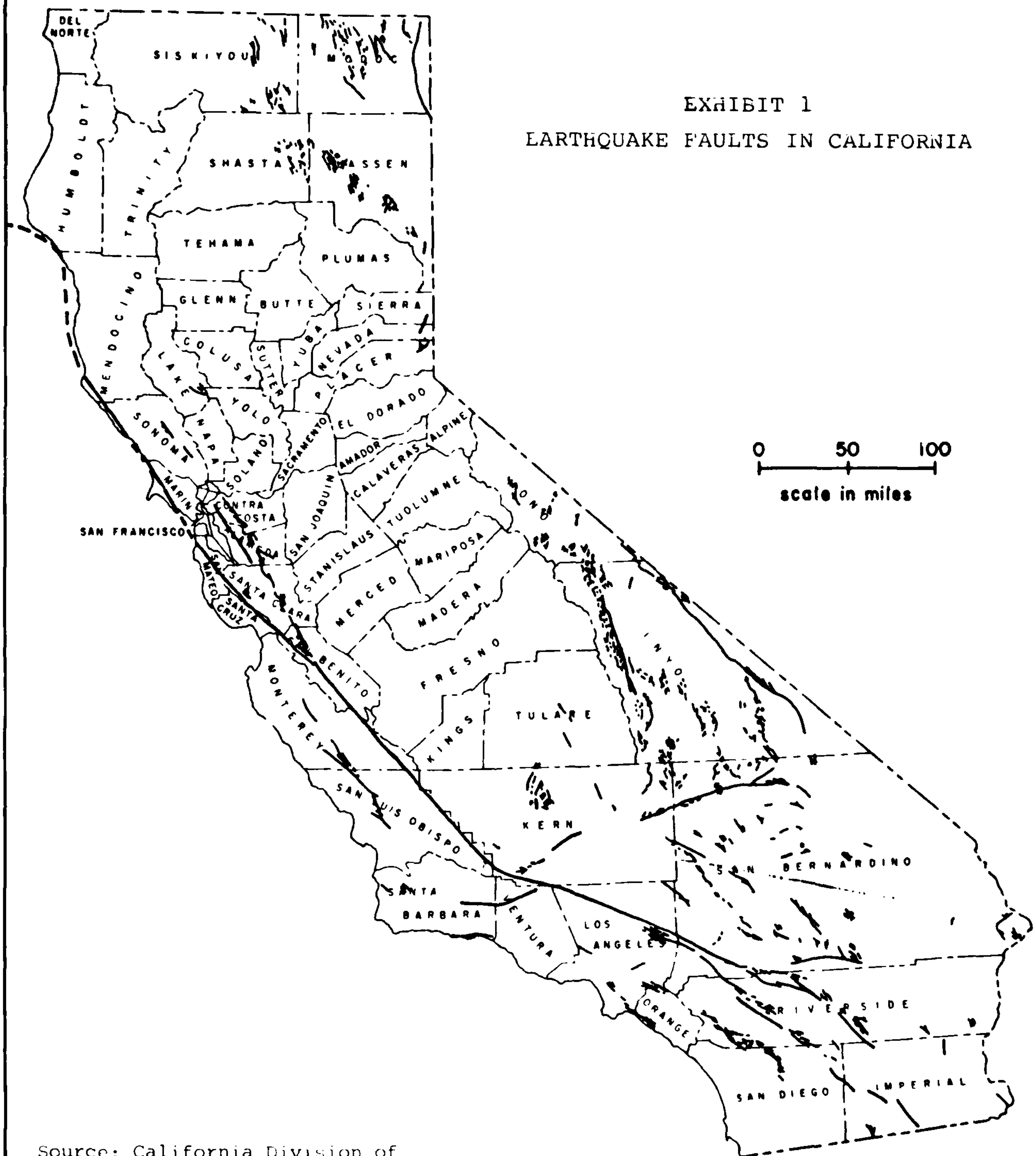
As illustrated in Exhibit 1, California has an extensive network of known earthquake faults concentrated along the coastal mountain ranges. Principal among these is the San Andreas fault which extends from an off-shore point near Cape Mendocino on the north coast, south easterly to a point near San Bernardino and perhaps as far south as the Salton Sea. There are a large number of smaller faults in the San Francisco Bay area and and in the Los Angeles area, both major population centers. A number of geologists have predicted that California will suffer another large earthquake before the end of this century.

EARTHQUAKE EXAMPLES

The research is based on estimates of the damage that historical or hypothetical earthquakes could inflict if they were to recur today. These earthquakes are examples of what might happen--they are <u>not</u> forecasts of expected future earthquakes. The nature of

EXHIBIT 1

EARTHQUAKE FAULTS IN CALIFORNIA



Source: California Division of
Mines & Geology

tectonic slippage along known faults is so complex that even if a repetition of an historical earthquake were to occur, the pattern of damage is likely to be very different. Nonetheless, historical facts lend credibility to the work and provide bases for quantitative estimates that might not otherwise be possible.

Four earthquakes have been selected for analysis:

1. An 8.3 Richter Scale magnitude earthquake on the San Andreas Fault, near San Francisco, similar to the 1906 earthquake;

2. A 7.5 Richter Scale magnitude earthquake on the Hayward Fault similar to but greater than the 1868 earthquake;

3. An 8.3 Richter Scale magnitude earthquake on the San Andreas Fault, near Los Angeles, similar to the 1857 earthquake; and

4. A 7.5 Richter Scale magnitude earthquake on the Newport-Inglewood Fault similar to but greater than the 1933 Long Beach earthquake.

These four examples have been selected because they represent maximum potential for destruction in urban areas and because they are centered on faults that could experience sufficient slippage to generate earthquakes of the magnitudes selected for the examples.

North San Andreas Fault

The 1906 San Francisco earthquake produced more damage and more deaths than any other California earthquake within recorded history. Buildings were destroyed or severely damaged from Santa Rosa southward to San Jose. Although damage was most severe in San Francisco, this was more a result of the fire than of the direct impact of the earthquake. Thanks to prompt action by the State in appointing a commission of distinguished scientists, the results of the earthquake are well documented.*

*Lawson, W. C. et al., The California Earthquake of April 18, 1906; Report of the State Earthquake Investigation Commission, The Carnegia Institution of Washington; Washington, D.C.: 1908 (Reprinted 1969).

The 1906 earthquake was triggered by a massive slip between the two sides of the San Andreas Fault. Surface faulting was observed over a distance nearly 400 km. The surface faulting extended from a point near Shelter Cove on the north California coast south easterly to the vicinity of San Juan Bautista. Almost all of the faulting occurred under land. However, the fault is believed to be under the Pacific Ocean between Shelter Cove and the vicinity of Point Arena and west of the entrance to San Francisco Bay. The maximum observed fault movement was 6.4 meters near Tomales Bay. Two major shocks occurred within about 1.5 minutes. The first shock built up over a period of about 40 seconds and then stopped. Ten seconds later, the second and more violent shock began and lasted for about 25 seconds. Although many aftershocks followed, none were serious. The main shocks were felt as far away as Coos Bay, Oregon, Winnemucca, Nevada and Los Angeles.

A repetition of the 1906 earthquake would cause severe damage throughout the San Francisco Bay area which is now inhabited by 5.5 million people. There is a real danger that the San Francisco peninsula would be isolated. Although the principal structures of the Golden Gate and Bay bridges are likely to survive, approach structures and their underlying soil are subject to failure. Other transportation facilities would fare little better, with the result that emergency measures would be needed to supply survivors and to evacuate the injured.

The Hayward Fault

During the nineteenth century, two large earthquakes occurred on the Hayward Fault: one in 1836 and another in 1868. Little is known about the earlier earthquake because of the Bay Area's small population at that time. Subsequent investigations suggest that surface breaks occurred from San Pablo to Mission San Jose (near Hayward)--a distance of 72 km.* The surface break associated with the 1868 earthquake was only about 40 km, centered on Hayward

*Louderback, G. D., "Central California Earthquakes of the 1830s", Bulletin of the Seismic Society of America; 37:33-74 (1947)

(extending approximately from the Piedmont district of Oakland to Mission San Jose). Even so, some investigators consider the two earthquakes to have been about equal in magnitude.

By 1868, there were nearly a quarter of a million people in the Bay Area. Damage from that earthquake was extensive on both sides of the Bay. However, observers noted that damage was greatest for structures on unstable or filled land.

No major earthquakes have been recorded on the Hayward Fault since 1868, but there has been considerable creep along the fault. This creep has been observed in Strawberry Creek,* in an aqueduct of the East Bay Municipal Utility District and in the bending of the Hetch-Hetchy aqueduct that serves San Francisco. Some persons theorize that continued creep relieves stresses along the fault and can help to avoid or postpone major slippage. Nonetheless, the Hayward fault is important today because of its strategic position separating the Bay Area from the rest of California. Major highways, railways, pipelines, and aqueducts all cross the Hayward Fault where they would be subject to substantial earthquake damage.

A 7.5 magnitude earthquake would be associated with a fault break approximately 100 km long--essentially the full length of the Hayward Fault. This break would extend from Pinole Point to a point ESE of San Jose.

South San Andreas Fault

The massive earthquake of January 9, 1857 was centered near Ft. Tejon which was about 100 km northeast of Los Angeles. Because the population of Southern California was small at that time, only cursory observations were made of areawide damage and of the extent of the faulting. Subsequent investigations** suggest that the fault rupture extended for 320 km from a point 30 km northwest of San Bernardino to a point NNE of San Luis Obispo. The earthquake caused damage in Los Angeles and was probably felt throughout Southern

*Near the border between Berkeley and Oakland

**Wood, H. O., "The 1857 Earthquake in California", Bulletin of the Seismic Society of America, 45:47-67 (1955).

California. A repetition of this earthquake today would likely kill and injure large numbers of people and produce substantial property damage. Major water supply canals and aqueducts that serve the Los Angeles Area cross or pass near the San Andreas fault in areas where severe faulting would be expected. Electric power lines and other life lines also cross the fault.

Of the four example earthquakes, the South San Andreas may be the most likely to occur. By studying offsets in stratified material, K. Sieh* has identified a sequence of 12 major events that likely occurred during the past 2,000 years at intervals of 100 to 200 years. The average interval is 140 years. It is now 125 years since the Ft. Tejon earthquake. Dr. Sieh's work suggests that another large earthquake is likely at some time during the next 75 years.

Newport-Inglewood Fault

Because the San Andreas fault passes no closer than 55 km from Los Angeles, a repetition of the Ft. Tejon earthquake would not cause as much damage to structures in the Los Angeles area as a smaller earthquake centered on one of the faults within the urban region such as the 1933 Long Beach earthquake on the Newport-Inglewood Fault, which had a magnitude of only 6.3. Such an earthquake would produce less area-wide damage but considerably more local damage.

Although not the most active fault in the Los Angeles basin**, an earthquake on the Newport-Inglewood Fault is likely to produce extensive urban damage. With an underwater epicenter, faulting for the 1933 earthquake may have extended for 26 km. The fault itself has been traced on land from a point north of Inglewood to a point near Newport Beach, a distance of 58 km. If it may be

*Davis, J. F. et al., Earthquake Planning Scenario for a Magnitude 8.3 Earthquake on the San Andreas Fault in Southern California, Special Publication 60, California Department of Conservation, Division of Mines and Geology, Sacramento: 1982.

**The San Jacinto Fault can easily claim this distinction.

presumed that the fault continues south under water*, then it could extend for a distance of 75 to 90 km, sufficient to account for a 7.5 magnitude earthquake. Such an earthquake could wreak havoc in Long Beach, Torrance, Huntington Beach, Newport Beach and as far as San Clemente. Port facilities could be severely damaged and isolated from the rest of the Los Angeles basin. Considerable damage could occur throughout Los Angeles and Orange Counties. In the view of some experts, this earthquake could cause more destruction than an 8.3 magnitude earthquake on the South San Andreas Fault.

TRANSPORTATION FACILITIES

The research is concerned with the potential impact of the four earthquake examples on transportation facilities in California and on the ability to effectively use those facilities after a major earthquake. The transportation systems of interest include:

- Highways;
- Railways;
- Pipelines (carrying natural gas and petroleum);
- Waterways and ports; and
- Airports.

These facilities are of two types: (1) those that have fixed routes which are combined into complex transportation networks and (2) those that consist of sets of point facilities. Highways and railways are the principal examples of networks. Each system has routes that traverse almost the entire state. In many locations facilities are redundant so that detours around some breaks in the lines are possible. Point facilities are locations where special services are provided such as at airports and seaports. If a point facility is lost, transport vehicles may seek a surviving facility in the damaged area or they may use a facility outside

*No underwater surface faulting has ever been identified.

of the damaged area in conjunction with other services to satisfy post-earthquake needs. Each transportation system has been treated in a unique way that is consistent with its resources and with its mode of operation.

Highway Transportation

Highways are the most ubiquitous form of transportation in California. Major urban areas are served by complexes of freeways, federal aid highways, state and county roads. Urban streets and rural roads are available to serve as detours around damaged highways. Temporary dirt or gravel roads can be quickly constructed to meet emergency needs. Nonetheless, it would be a gross error to presume that there are sufficient highways to meet all post-earthquake needs.

Two types of highway damage are of interest: bridge damage and roadway damage. Bridges can be further divided into bridges that carry a highway of interest and bridges that cross over a highway of interest. Damage to a bridge that is carrying an important roadway can weaken the structure so that it can carry only light vehicles, or the structure can fail or be so weakened that it cannot be safely used by any vehicles. In either situation continued heavy use will depend on locating a suitable detour. A bridge that crosses a major roadway can fail by dropping a span onto the roadway and blocking it; or the bridge may be weakened so that its use is denied or restricted. So long as the span remains in place there is no impediment to the undercrossing highway.

Roadway damage can result from failure of the roadbed or failure of an embankment next to the road. Roadbed failure can take the form of soil slumping under the pavement, settling, cracking or heaving of pavement blocks or other movements that make the roadway unusable. Embankment failure can produce slides across the roadway that block it.

Both bridge and roadway failures can be temporarily repaired. Damaged bridges can be shored up with timber or other structural materials. Temporary scaffolding can be erected to support spans whose piers or columns are displaced. Fallen spans can be removed. Roadways can be repaired by clearing slides, rebuilding fills, cutting temporary detours, removing broken paving blocks and other actions. The temporary repairs do not fully restore highways to pre-earthquake capability, but they do permit limited use which can be sufficient to meet emergency needs.

If there are but one or a few highway failures, equipment, crews and material can be marshalled and even complex repairs can be completed in a few hours. However, the many highway failures caused by a major earthquake will exceed the numbers of available crews and therefore require considerably longer to repair.

Railroad Transportation

California is served by five major railroads: (1) Atcheson, Topeka and Santa Fe (ATSF), (2) Burlington Northern (BN), (3) Southern Pacific (SP), (4) Union Pacific (UP), and (5) Western Pacific (WP)*. All except the BN serve one or both of the major population centers. There are east-west lines into both San Francisco and Los Angeles and north-south routes in the Central Valley and along the coast. Many areas are served by parallel routes so that detours are possible; however, there are key bottlenecks in several mountain passes. There is a single route over the Tehachapi Pass between the Central Valley and the Mojave Desert; a single coastal route between San Francisco and Los Angeles and only two routes through the Berkeley hills--both crossing the Hayward Fault.

Railroad damage is treated in the same fashion as highway damage, with separate analyses of bridge and roadbed damage. Both

*On September 13, 1982, the Interstate Commerce Commission approved the merger of the WP into the UP.

modes must be considered for grade separated crossings between railways and highways. In addition, railroads have yards, terminals and maintenance facilities that are used to gather, sort and disperse cars and to repair rolling stock. These, too, are subject to earthquake damage and to blocking by debris.

Railroads are accustomed to dealing with emergencies on their lines. Derailments are almost daily events. Slides and washouts are common in mountainous terrain and flooding occurs in canyons and valleys. Railroads maintain emergency crews and equipment to deal with these problems. In the past, railroads have responded promptly to earthquake damage and they have quickly restored service. For example, the Tehachapi earthquake of July 21, 1952 caused extensive damage to four tunnels on the critical rail link between the Central Valley and the Mojave Desert. This line normally carries all ATSF and much SP traffic between Northern and Southern California. Repair work began at once and by August 16--26 days later--a shoofly bypass had been constructed around the worst damage, so that limited traffic could resume. By December 16 repairs were complete and full traffic was restored. This feat was accomplished by concentrating resources on the single line. Damage in a dozen different areas could not be treated so expeditiously.

Pipeline Transportation

Pipelines transport natural gas, petroleum and petroleum products in one way networks. Petroleum and petroleum products move in large volumes between producing fields or ocean terminals and refineries, and between refineries and bulk terminals. Final distribution to retail outlets is by truck. In contrast, natural gas pipelines feed distribution stations where pressures are reduced and gas is directed through a network of smaller lines to retail customers. The research was restricted to major pipelines that deliver natural gas, petroleum and petroleum products to large distribution centers.

Pipelines are buried underground, except when they cross streams or gorges or emerge for connection to compressor or pumping stations. The damage that an earthquake inflicts on the pipeline depends on the intensity of the shock and the characteristics of the soil in which the pipeline is buried. Pipelines are expected to fail if they cross fault lines where differential slipping occurs. Pipelines are also likely to fail at interfaces between soil which does not fail and that which does. Other failures can be caused by damage or displacement to compressor or pumping stations and to above ground structures.

Pipeline failures can cause leakage and spillage that presents the potential for fire as well as environmental hazards for earthquake survivors. Spillage can be controlled by automated shut off valves that are actuated by falling pressure. These have been installed in many lines. Alert operators can isolate ruptured sections of pipe from control stations provided they have electric power. The alternative of manually closing key valves is a last resort.

Pipeline companies also have emergency crews that can cope with a limited number of breakages. Their first priority is to stop leaking. Thereafter, they direct their energies to locating and repairing breaks. Locating breaks in underground lines can be a problem; however, sophisticated techniques are available that use special gases and pressure tests.

Airports

Airports are discrete facilities that can be treated individually and independently. California has a large number of commercial, military and general aviation airports and private landing strips. These can suffer earthquake damage in a variety of ways:

- Control towers and terminal buildings can be damaged or destroyed;

- Ground failure under runways or aprons can make these unusable;
- Loss of electric power can prevent the use of sophisticated control equipment;
- Ruptured fuel tanks and lines can eliminate refueling capability; and
- Fault breaks across runways or aprons can make them unusable.

All of these failure modes will be represented in the earthquake examples.

Although airports do have maintenance personnel and equipment, they are not prepared to cope with extensive earthquake damage. At best, they can perform minor runway and apron repairs and initiate emergency operations using surviving facilities. Because of the potential extent of airport repairs, it is unlikely that they would be undertaken until other emergency repairs are complete.

Water Transportation

The analysis of water transportation is concerned with two types of facilities, ports and waterways. Ports are discrete facilities that can be treated more or less like airports. Major concerns focus on damage or destruction of piers, moorings, quay walls, bulkheads, structures and channels. Experience in past earthquakes reveals that pile supported structures survive reasonably well if piles are driven to hard soil or rock. Quays and bulkheads often fail because earth fill behind the walls tends to slump or liquify, allowing water pressure to topple vertical barriers. Channels may be blocked by earthquake induced slumping on channel walls.

The surviving facilities in a port are useful only if there is ground access for inbound and outbound cargo. Ground failure adjacent to a port, blockage by debris and failure of access roads

and railroads can render a port as useless as its destruction. Therefore, access routes must be examined as well as the port facilities.

Waterways can fail through channel slumping and channel blockage. Deep channels dredged in soft mud are subject to earthquake induced slides that can limit the draft of the ships that can enter the harbor or even render them inaccessable to all shipping. Waterways can be blocked by fallen bridges. Thus all crossing structures must be examined to assure that a waterway is usable.

TIME SCALE

Given sufficient time, earthquake damage can and most probably will be repaired. Typically, repair crews are dispatched as soon as the damage is assessed. The order of priority for emergency action is:

1. Rescue survivors;
2. Neutralize or eliminate hazards to life such as leaking pipelines;
3. Establish blockades to prevent use of hazardous structures;
4. Make emergency repairs to facilities critical to survival;
5. Make emergency repairs to facilities that may pose health hazards;
6. Establish emergency procedures to provide water, food, medical care and other essential services for survivors;
7. Restore electric power;
8. Begin emergency repairs to other facilities.

The time at which each activity is begun will depend on the extent of the earthquake damage and the number, size and skill of the emergency crews.

This research does not deal with the recovery process. Attention is focused on transportation capability after Step 3. At this time, damage has been assessed, damaged facilities have been blockaded or cordoned off in some fashion. Communications are sufficient to limit traffic to emergency means, to dispatch traffic to meet critical needs and to designate available routes. Such a state might be reached eight to twelve hours after a major earthquake. Panic would be under control and the survivors would be ready to turn their attention constructively to survival issues.

SOURCES OF DATA

The analysis depended on two types of data: the location and characteristics of transportation facilities; and the potential damage to these structures as a result of the example earthquakes. Structure data for different transportation facilities were drawn from several sources. The project team sought listings of structures that were complete, without being overwhelming. Complete sets of data were collected for all transportation modes except highways. There are about 25,000 highway structures in the State of California with roughly half of these on state-maintained routes and half on county roads and city streets. Because of the magnitude of these facilities, a smaller sample was sought.

The sample highway bridge data were supplied by the California Department of Transportation (Caltrans) from an evaluation of all bridges on the State system that was undertaken after the 1971 San Fernando earthquake. The evaluation revealed that 1239 bridges had insufficient resistance to seismic shocks. A program was inaugurated to improve their seismic resistance* by restraining hinges

*Mancarti, G. D., "New Concepts in Earthquake Retrofitting of Highway Bridges," Caltrans.

and modifying bearing supports. At the time of this report, the retrofitting program is approximately half complete. The project team used the set of 1239 bridges as representative of highway bridges most likely to fail in a major earthquake.

Data on railroad bridges were taken from track charts published by the different railroads. These charts locate each bridge by line and mile post. Locations were established by plotting bridges on large scale maps. General bridge characteristics were listed in the track charts. These data were augmented by personal inspections of a number of structures in critical locations. All railroad bridges were inventoried that are located in areas of potentially high seismic shock for any one of the four example earthquakes.

Pipeline data were taken from maps supplied by the American Petroleum Institute. No detailed data were available on soil conditions for pipelines. Only general soil data could be used to identify discontinuities where pipe failures might occur.

Resource data for airports and seaports were provided by FEMA from their national resource files. These data included location, function, structural characteristics, size and operational data. Some of these data were checked to verify size and characteristics. The structural data were incomplete.

The analysis of earthquake damage was drawn from many sources. Reports on historical California earthquakes have given much useful information on the types of structures that fail and the manner in which they fail. Reports of particular value include the Carnegie Report*, the Caltrans reports on the San Fernando earthquakes**,

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*Lawson, W. C. et al. op. cit.

**Division of Highways, The Effect on Highways of the San Fernando Earthquake, February 9, 1971, State of California, Sacramento; September 1971.

and reports by Steinbrugge on the Tehachapi earthquakes.*

There have been several useful studies of the impacts of potential earthquakes in California. In 1972 and 1973, the National Oceanic and Atmospheric Administration sponsored studies of the potential damage to transportation and other key emergency resources that might be caused by two Northern California and two Southern California earthquakes.** More recently, in 1982 the California Bureau of Mines and Geology has studied the impact that major earthquakes on the North and South San Andreas Fault might have on critical lifelines.*** These studies also addressed the time necessary to restore certain critical highways.

The United States Geological Survey has generously provided use of its programs for estimating earthquake intensity. These programs, developed by Dr. Jack Evernden, calculate earthquake intensity (Rossi Forel Scale) as a function of length of faulting, depth of faulting, distance from fault, soil conditions, and other factors. A related program was also used to prepare iso-seismal maps using general soil characteristics for 1/2 minute squares.

Finally, the project team has called on earthquake engineering experts for estimates of structural damage as a function of structure type and earthquake intensity.

All of the data are subjective to a greater or lesser extent. No test borings were made to ascertain what the soil is really like under the foundations of key structures. No calculations were made to estimate the impacts of earthquake induced accelerations on

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*Steinbrugge, K.V., and D.F. Moran, "An Engineering Study of the Southern California Earthquake of July 21, 1952 and Its After-shocks", Bulletin of the Seismological Society of America, Berkeley: 1954

**Algermissen, S.T., A Study of Earthquake Losses in the San Francisco Bay Area, National Oceanic and Atmospheric Administration, Washington: 1972, and A Study of Earthquake Losses in the Los Angeles, California Area, 1973.

***Davis, J.F. et al., op. cit.

different structures. As a result, statements cannot be made to the effect that any particular structure is likely to fail or to survive a particular earthquake. Rather, similar structures are grouped and statements are made about the likelihood that one or more structures in a group will fail as a result of an example earthquake.

ANALYTICAL METHOD

An analytical method was devised that examined transportation facilities in more detail than has been possible in past earthquake impact assessments. Two new techniques were introduced:

1. Transportation networks were divided into specific route segments so that potential damage could be investigated for each route segment, and

2. Critical structures were examined as a group for each route segment so that meaningful statements could be made about a route segment even without definitive information about each structure.

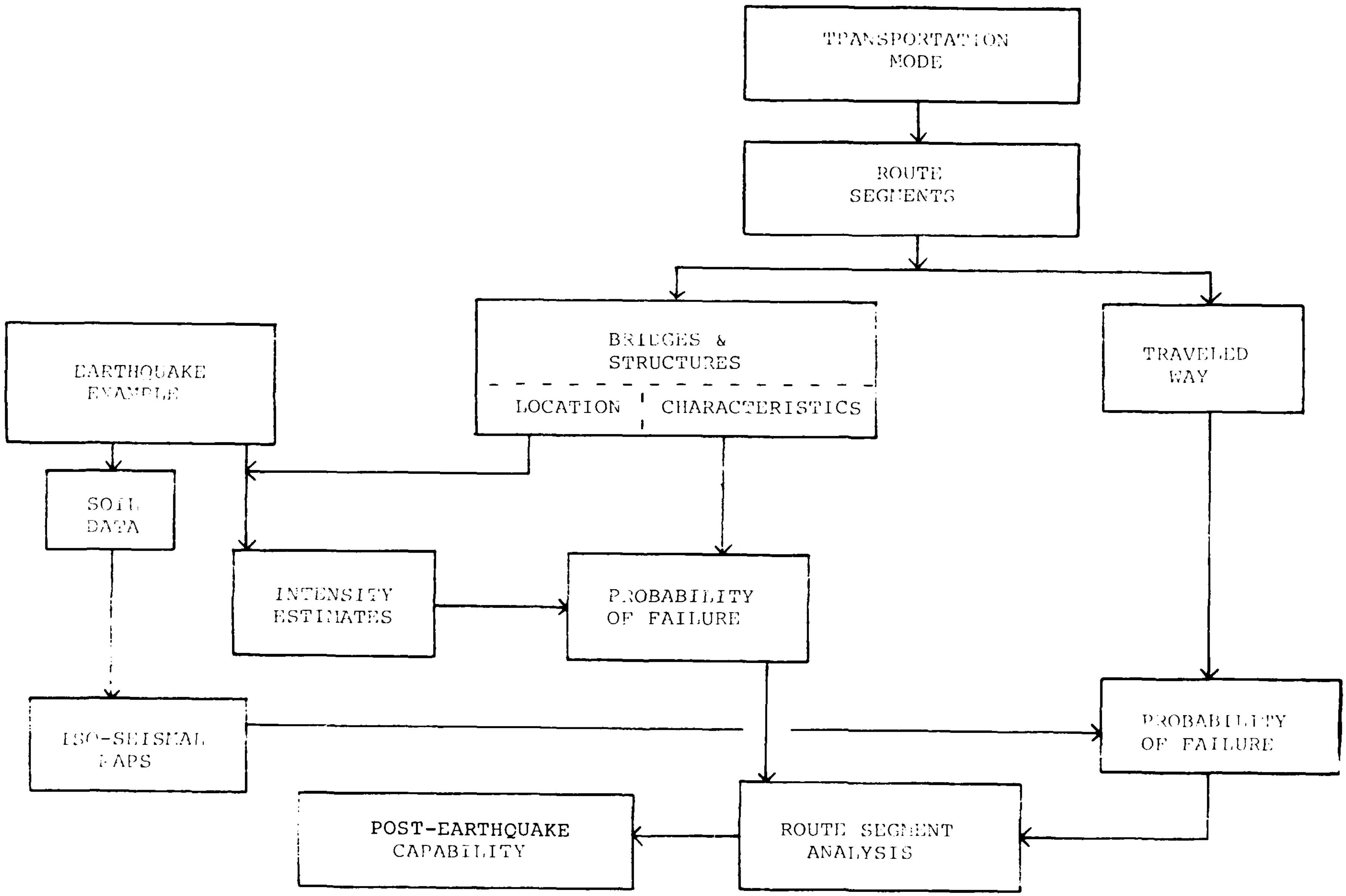
Point facilities like airports and ports were treated in a similar fashion to past studies.

Exhibit 2 illustrates the analytical method. The process begins by selecting an earthquake example and a transportation mode. Some preparatory analysis was performed for the earthquake examples that was independent of transportation mode. Using its soil data, the USGS prepared a set of iso-seismal plots for each of the four earthquakes. These were reduced to maps that indicate areas of potentially damaging earthquake intensity. These maps are discussed and presented in Chapter III.

Some analysis of the transportation modes was also independent of earthquake scenarios. This took the form of preparatory definitions of modal resources. The network of traveled way for each transportation mode was divided into interconnected route segments.

EXHIBIT 2

ANALYTICAL METHOD



Each route segment was described by its endpoints, the nature of the traveled way and an estimate of its capacity in vehicles per day or a related measure. Bridges and structures were identified for each route segment. Data on each structure included its location, by latitude and longitude, structural and use characteristics.

Separate techniques were used to assess traveled way and structures. Because of its continuous nature, damage to traveled way was assessed graphically using the iso-seismal maps. In areas of high expected earthquake intensity, consideration was given to the nature of the terrain and to the quality of the soil underlying the traveled way. In the absence of reliable soil data, judgments were made using other earthquake experience and the opinions of experts. To the extent possible, probabilities of failure were assessed.

More detailed work was possible with structures because they are more or less discrete facilities. The locations of all structures were submitted to USGS, for estimates of earthquake intensity at each structure site. These estimates were independent of soil conditions. Failure estimates were based on earthquake intensities, structure characteristics and such soil data as were available. In some instances, sites were visited to aid in interpreting sparse data. This work is described in Chapter II.

The structure and traveled way damage estimates were combined in an assessment of the probability that each route segment would survive the earthquake. Traveled way was examined first. Opportunities for detours around the potential failures were explored. If no suitable detour was available, then temporary repairs were considered. The likelihood that all structures would survive was calculated in two parts--first for structures that form part of the route segment and then for those that cross it.

If p_1 is the probability that structure 1 will be damaged beyond use, the $1-p_1$ is the probability that it will survive.

If two structures, 1 and 2, are acted on independently by the earthquake, then $p_1 p_2$ is the probability that both will fail and $(1-p_1)(1-p_2)$ is the probability that both will remain standing. Therefore, P_S, the probability that all of the structures along a route segment will survive is:

$$P_S = \prod_{i-1}^{n} (1-p_i)$$

where: N is the number of structures along the route segment.

Post earthquake capability was estimated by assessing the capacity of each surviving route segment and then assembling the route segments into a surviving network. Judgments were made about access to survivor areas from the surviving networks. The question of post earthquake mobility in damaged areas has not been addressed. The results of the analysis are described for each of the four earthquake examples in Chapters IV through VII.

II. TRANSPORTATION NETWORKS

This chapter describes the development of the modal transportation networks and the selection of the route segments used in the analysis. The focus of the study is on intercity transportation, principally movements into and out of the State's two major metropolitan areas--San Francisco and Los Angeles. Major trunk routes are of particular interest. The analysis is concerned with establishing post earthquake connected networks for each transportation mode. A transportation segment has no greater capability than its connections. Unless a segment is attached to a surviving network, it cannot support the evacuation of earthquake survivors or the transportation of food, water and emergency supplies. Therefore, branch routes to mines and other unique facilities are not considered, nor are secondary routes capable of carrying only light traffic. Access within each metropolitan area is an important consideration.

THE HIGHWAY NETWORK

The highway network is made up of heavy duty traffic arteries throughout the State of California. The route segments are comprised of Interstate and Defense highways, Federal Aid primary and secondary highways and State highways. In urban areas, most of the highways are built to freeway standards. Although these roads are particularly vulnerable to overcrossing bridge failures, they were selected because in many cases they have usurped the right-of-way of the lower standard routes that they superseded. In some instances, there are parallel surface routes; in most, there are not. Where parallel routes exist along all or part of a route

segment, the lower quality route can be used for detours around damage on the higher quality route. A variety of different highway types have seen selected in rural areas. These include grade separated interstate routes, three and four lane highways and high quality two lane highways. Their common criterion is that each must now carry a substantial amount of truck traffic. Truck routes have easier grades and fewer sharp curves than other routes. The surfaces tend to be heavier, and they are kept in good repair. Surviving route segments must be capable of supporting substantial post earthquake traffic.

The highway network is illustrated in Exhibit 3, located in the pocket in the back cover. Some of the north-south intercity routes are:

- Interstate 5 extending from Yreka on the Oregon border through Sacramento, Stockton and Los Angeles to San Diego;

- U.S. 101 extending from Crescent City near the Oregon border through San Francisco (across the Golden Gate Bridge) to Los Angeles; and

- U.S 395 extending from Alturas near the Oregon border through Reno, San Bernardino, and Riverside to San Diego.

Additional north-south routes, such as State Routes 99 and 1 carry substantial amounts of traffic, but have been partly superseded by other routes. State route 99, for example, has been replaced by Interstate 5 north of Red Bluff. From Red Bluff, Route 99 extends southward through Sacramento, Stockton, Fresno and Bakersfield and then merges into Interstate 5 just north of Grapevine.

Principal east-west routes include the following:

- Interstate 80 from Reno through Sacramento to San Francisco (across the San Francisco-Oakland Bay Bridge;

- U.S. 50 from Lake Tahoe to Sacramento; discontinuous to Stockton and then continuing as Interstate 580 to Oakland and Interstate 80;

- Interstate 40 from Needles to Barstow; continuing as State Route 58 to Bakersfield and Interstate 5;
- Interstate 15 from Las Vegas through Barstow to U.S. 395 (Interstate 15 is designated as the surviving route);
- Interstate 10 from Blythe through San Bernardino to Los Angeles; and
- Interstate 8 from Yuma, Arizona to San Diego.

There are considerably more routes that need to be considered in the San Francisco and Los Angeles metropolitan areas. These include freeways and major arterial streets. In the San Francisco Area (Exhibit 4), there are three major north-south routes on the San Francisco peninsula--U.S. 101 (Bayshore Freeway), State Route 82 (El Camino Real) and Interstate 280. In addition, State Route 1 serves the coastal cities. The East Bay is served by State Route 17 and Interstate 580. There is no single surface street that provides arterial north-south service for the length of the East Bay--San Pablo Avenue comes close. In addition to the Bay Bridge, there are three other Bay crossings--the Richmond - San Rafael Bridge, the San Mateo Bridge and the Dumbarton Bridge. All carry state routes which are tied into the network. The San Jose area is served by a network of freeways and arterial streets. Interstate 280 passes through San Jose, interchanges with U.S. 101 and then continues north as Interstate 680 to Benecia and to Interstate 80. State Route 17 passes through San Jose and continues south to Santa Cruz. A number of arterial streets carry heavy traffic and could easily serve as detours.

Los angeles is served by an extensive network of freeways and arterial streets (Exhibit 5). There are three major east-west routes in the valley connecting Los Angeles with San Bernardino--Interstate 10 (The San Bernardino Freeway), Route 60 (The Ramona Freeway), and State Route 66-Interstate 210-U.S. 101-State Route 134 (Foothill Boulevard-Ventura Freeway). There are three routes passing through Los Angeles from northwest to southeast--State

Exhibit 4
HIGHWAY DETAILS IN SAN FRANCISCO BAY AREA

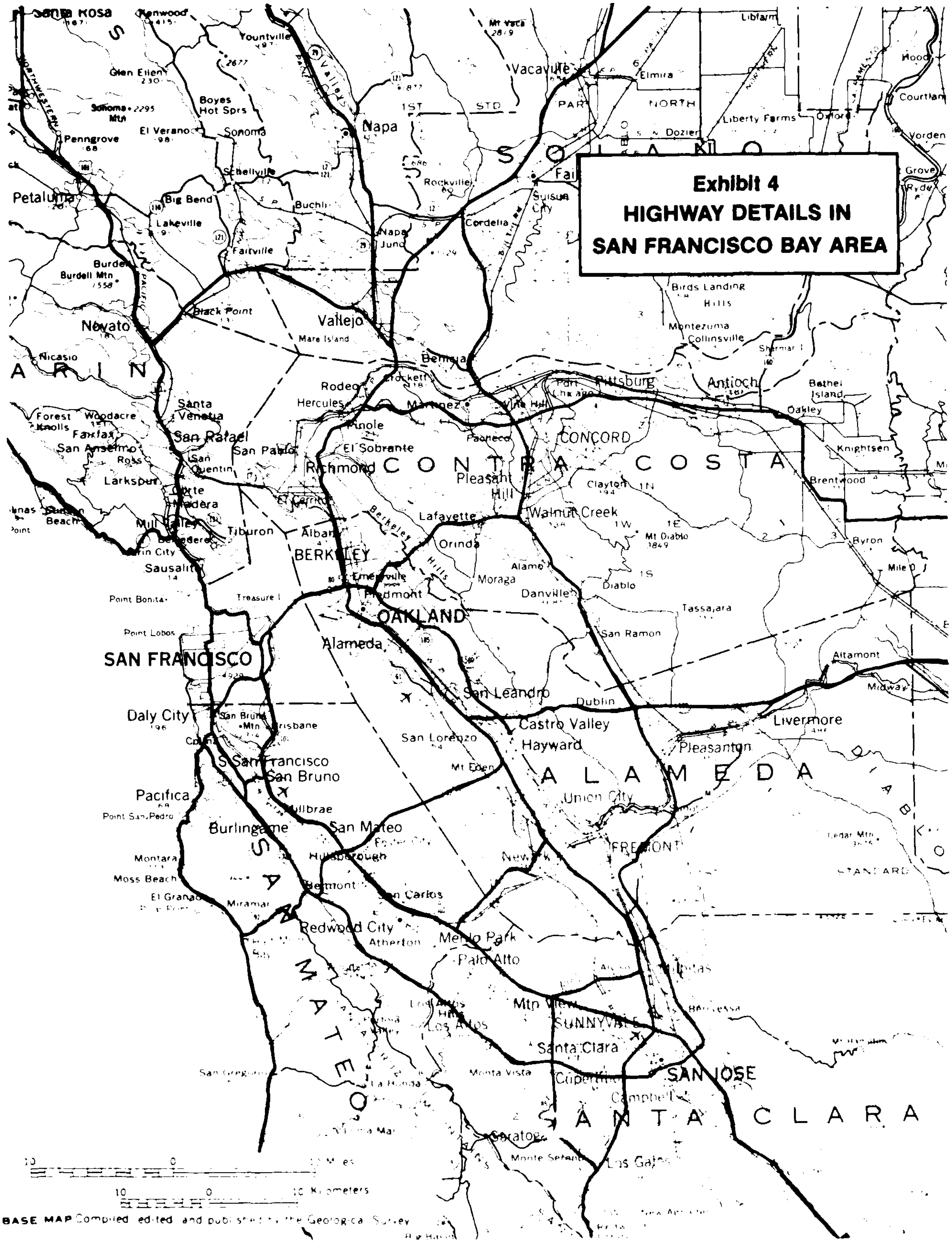
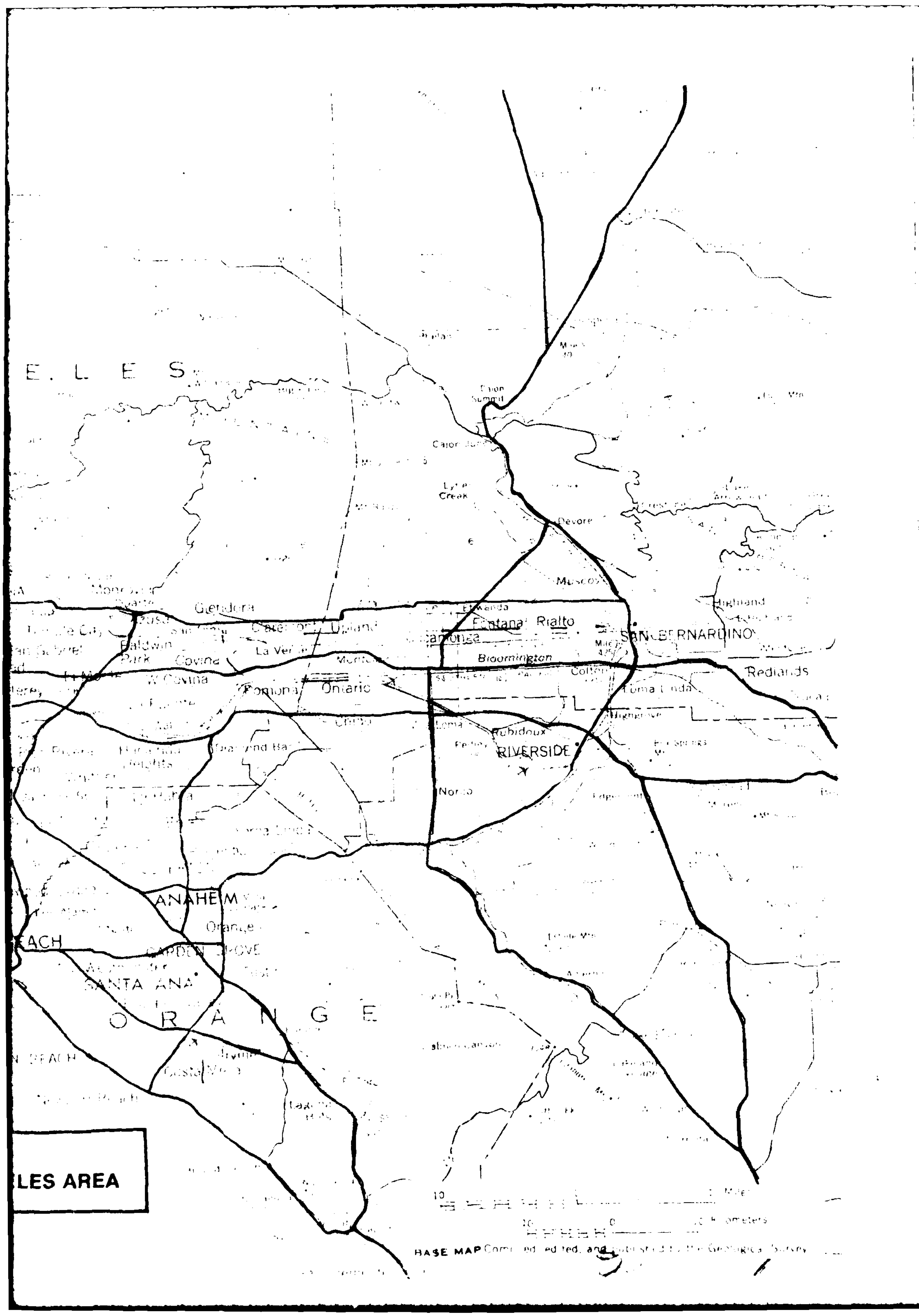


Exhibit 5
HIGHWAY DETAILS IN LOS ANGELES AREA



E L E S
Cajon Summit
Cajon Junction
Lytle Creek
Devore
Muscoy
Monrovia
Duarte
Glendora
Azusa
Claremont
Upland
Etiwanda
Fontana
Rialto
Cucamonga
SAN BERNARDINO
Highland
Baldwin Park
Covina
La Verne
Montclair
Bloomington
Colton
Redlands
W Covina
Pomona
Ontario
Loma Linda
Highgrove
Chino
Rubidoux
Diamond Bar
Pedley
RIVERSIDE
Norco
ANAHEIM
Orange
BEACH
GARDEN GROVE
SANTA ANA
O R A N G E
Irvine
Costa Mesa
LES AREA
BASE MAP
Miles
Kilometers

Route 1, Interstate 405 and Interstate 5. These routes join at San Juan Capistrano and continue southeast as a single highway (Interstate 5) to San Diego. There are five north-south routes that traverse Los Angeles connecting the San Bernardino Corridor with the Coast--State Route 11 (Harbor Freeway), State Route 7 (Long Beach Freeway), State Route 19 (Lakewood Boulevard), Interstate 605 (River Parkway) and State Route 57 (Orange Freeway). A number of arterial streets paralleling these routes can provide detours over parts of the route segments.

The traffic carrying capability of the highway network depends entirely on the demands that are placed on it. Few highway segments are saturated with intercity traffic. Most traffic is local--traveling only short distances. For metropolitan areas, the heavy concentrations of traffic are all internal--the average length of urban trips is five miles or less. If, through good communication and effective enforcement, highway traffic could be reduced to emergency needs, traffic levels would be low and post-earthquake needs could be met with a small fraction of the highways that are available in the metropolitan areas today.

Because traffic with different origins and destinations interacts at each route junction, highway capacity can best be expressed in terms of individual route segments. The vehicular capacity per lane depends on the highway geometry and on the nature of the traffic. Nonetheless, the following traffic volumes reflect the capacities of different types of highways.

Freeway/Interstate	1,600-2,000 automobiles/lane/hour
Expressways	1,000-1,400 automobiles/lane/hour
Arterial Streets	600-1,000 automobiles/lane/hour

On level terrain a truck typically takes as much highway space as two or three automobiles. In mountainous terrain, a truck may take as much space as five to ten automobiles.

THE RAILROAD NETWORK

As illustrated in Exhibit 6 (in the back cover jacket) the railroad network resembles the highway network because it must accommodate to the same terrain. All railroad routes are included in the network except branch lines that lead to isolated facilities. Secondary lines, such as the Southern Pacific's Montalvo-Saugus* line which is now used for car storage, are included because they can be quickly made available in times of need. The railroad network is best described in terms of the five major railroads that serve the state: Southern Pacific (SP), Atcheson, Topeka and Santa Fe (ATSF), Union Pacific (UP), Western Pacific (WP), and Burlington Northern (BN). The lines of each railraod are separately identified in Exhibit 6 by a code. Routes of different railroads (or of the same railroad) often cross without providing the opportunity to switch from one line to another. If there is no grade separation, an emergency connection can be quickly made. Terminal and switching company lines are useful for pick up and delivery, and are considered when addressing questions of access.

The SP has by far the largest track network in the State. Major routes enter the State from the Oregon border, Reno and Yuma, Arizona. The SP maintains a major classification yard at Roseville (northeast of Sacramento), the intersection between the routes from the north and from the east. From Roseville, trains are dispatched to and received from the San Francisco Bay Area, the Central Valley, Los Angeles and the southern route east via Yuma. The SP operates a major terminal in Oakland that extends from San Leandro to Berkeley. The SP's other major California classification yard is at Colton (near San Bernardino) where traffic is dispatched to and received from the east, via Yuma, and the Central Valley for blocking and train make up to serve the Los Angeles Basin. The SP also has a coastal route that serves San Francisco and continues south to Los Angeles.

*Montalvo is a junction with the coast route near Oxnard and Saugus is near San Fernando.

The ATSF route enters California from Arizona at Needles and continues west to Barstow, where it branches with one line going south to San Bernardino and then to Los Angeles and San Diego. The other branch continues west to Mojave where trackage rights over the SP's Tehachapi Pass route give access to the Central Valley and to Richmond in the San Francisco Bay Area. The ATSF has a major classification yard at Barstow and terminals at Los Angeles and Richmond.

The Union Pacific serves Southern California with a route southwest from Las Vegas to Barstow and then into San Bernardino and Los Angeles. It is the only railroad to serve the Terminal Island port facilities. The UP has yard and terminal facilities in Los Angeles and Barstow.

The Western Pacific, which will be operated as a division of the UP after the merger takes place, has a line from northern Nevada to Sacramento, Stockton and Oakland. It also has trackage rights over the SP to Salinas and to the San Francisco Peninsula. The WP has major yard and shop facilities in Sacramento and a terminal in Oakland.

The Burlington Northern has a single line in California that enters the State south of Klamath Falls, Oregon and continues south to Bieber in the northeastern part of the state where traffic is interchanged with the WP.

Railroad line capacity depends on the number of tracks, the length and location of passing sidings, train speeds and speed variations, the nature of the traffic carried, and on the signalling and dispatching technique in use. There have been theoretical studies of line capacity that are generally based on balanced traffic in both directions and on precision dispatching.* Practical capacities are always somewhat lower. The following capacities are suggestive of the trains per day in both directions that undamaged rail lines can carry with reasonable attention to operating efficiency:

*See, for example, Peat, Marwick, Mitchell & Co., Parametric Analysis of Railway Line Capacity, prepared for Federal Railroad Administration, Washington: 1975.

Single track, manual train orders	10-12 trains/day
Single track, automatic block signals	12-16 trains/day
Single track, centralized traffic control	30-35 trains/day
Double track, automatic block signals	60-72 trains/day.

Loss of communication and damage to track and signalling could greatly reduce track capacity. Even so, it seems likely that 10 to 12 trains per day could be operated over any open line.

NATURAL GAS PIPELINES

Although natural gas is produced within California, the largest source is from interstate pipelines that bring natural gas from fields in Texas and Oklahoma. With the deregulation of gas prices, the exploration rate has accelerated and new sources are being found. Nonetheless, the State is still heavily dependent on outside sources. The out-of-state natural gas enters California from Arizona through three major pipelines near Blythe and Needles. Gas is transported under pressures of about 55 atmospheres to terminals where pressure is reduced for distribution to industrial and residential users. It is not customary to store large volumes of gas near major markets, but there are four underground storage fields in Southern California and one in Northern California. In addition, there are a number of large gas holders in northern California that can be used for storage.

The analysis is concerned with the high pressure pipeline network that delivers natural gas to distribution terminals. Because of the one-way movement of gas, attention is focused on areas of potential earthquake damage in and around the two metropolitan areas. Exhibits 7 and 8 illustrate the high pressure gas pipelines in Northern and Southern California. Natural gas service to the San Francisco Bay Area is provided by the Pacific Gas & Electric Co. The main supply line comes from the east through the Amador Valley, south of Livermore, to a terminal in Fremont. Here the line divides, supplying Oakland and

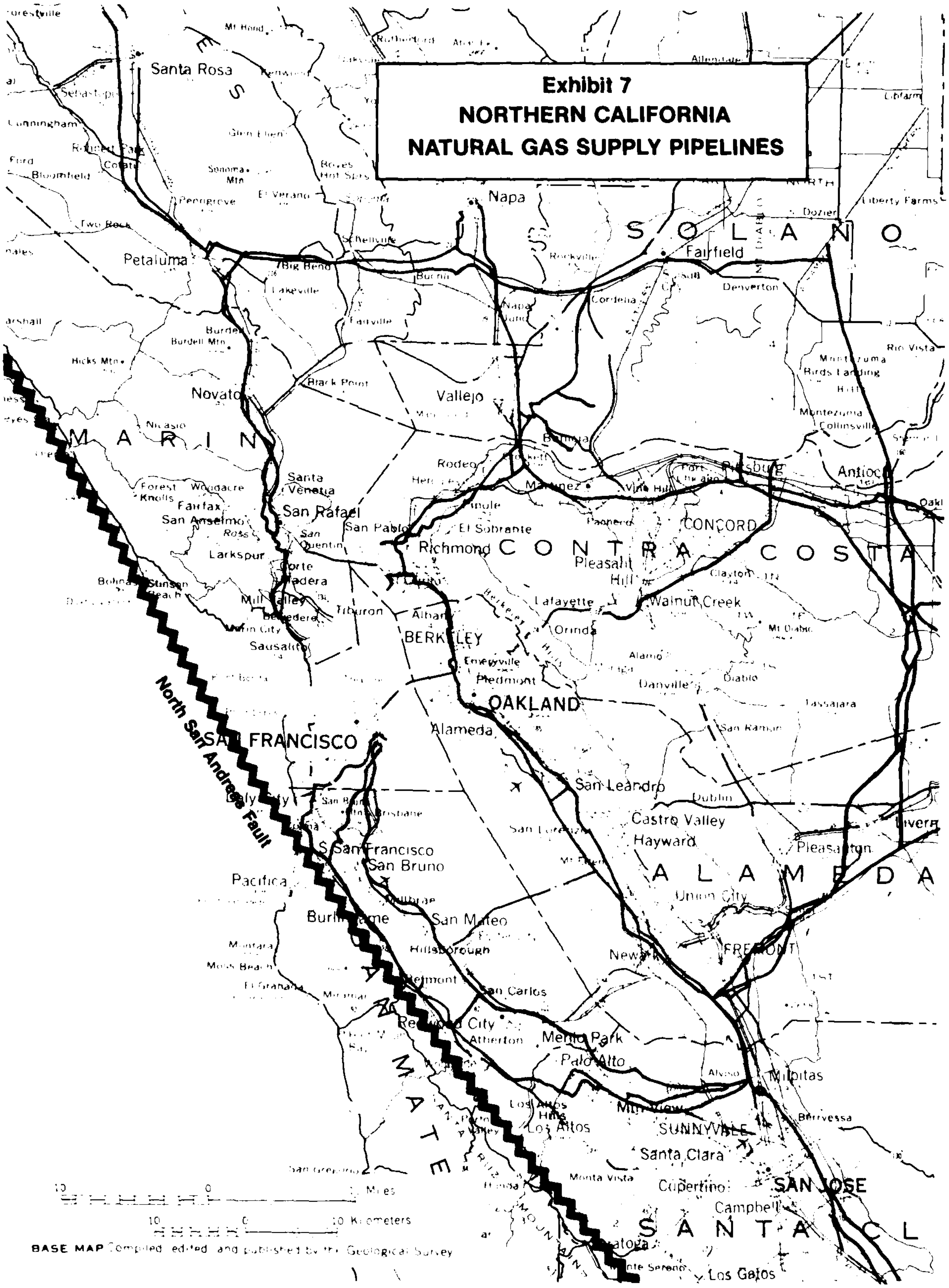
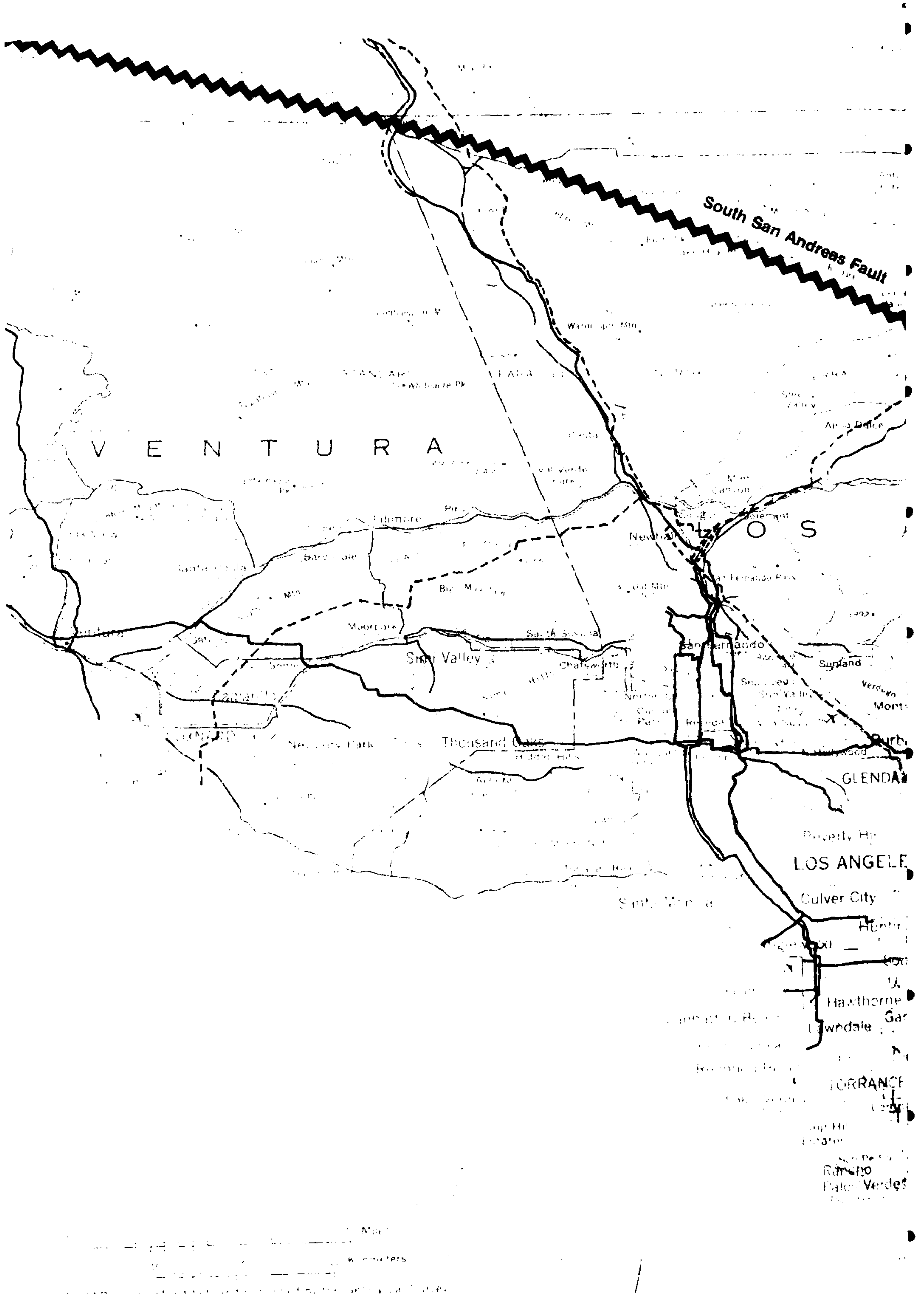


Exhibit 7
NORTHERN CALIFORNIA
NATURAL GAS SUPPLY PIPELINES
North San Andreas Fault
Santa Rosa
Petaluma
Napa
Fairfield
Vallejo
Novato
MARIN
SOLANO
San Rafael
Richmond
CONTRA COSTA
CONCORD
Walnut Creek
BERKELEY
OAKLAND
Alameda
SAN FRANCISCO
San Leandro
Castro Valley
Hayward
ALAMEDA
Pleasanton
South San Francisco
San Bruno
Pacifica
San Mateo
Redwood City
Menlo Park
Palo Alto
Milpitas
SUNNYVALE
Santa Clara
SAN JOSE
Cupertino
Campbell
Los Gatos
Antioch
Pittsburg
Martinez
Fremont
Newark
10 0 10 Miles
10 0 10 Kilometers
BASE MAP Compiled, edited, and published by the Geological Survey



South San Andreas Fault
V E N T U R A
L O S
Fillmore
Santa Paula
Moorpark
Simi Valley
Chatsworth
Thousand Oaks
Newhall
San Fernando
Sunland
Burbank
GLENDALE
LOS ANGELES
Culver City
Hawthorne
Lawndale
TORRANCE
Rancho
Palos Verdes
Santa Monica
Agua Dulce
Val Verde

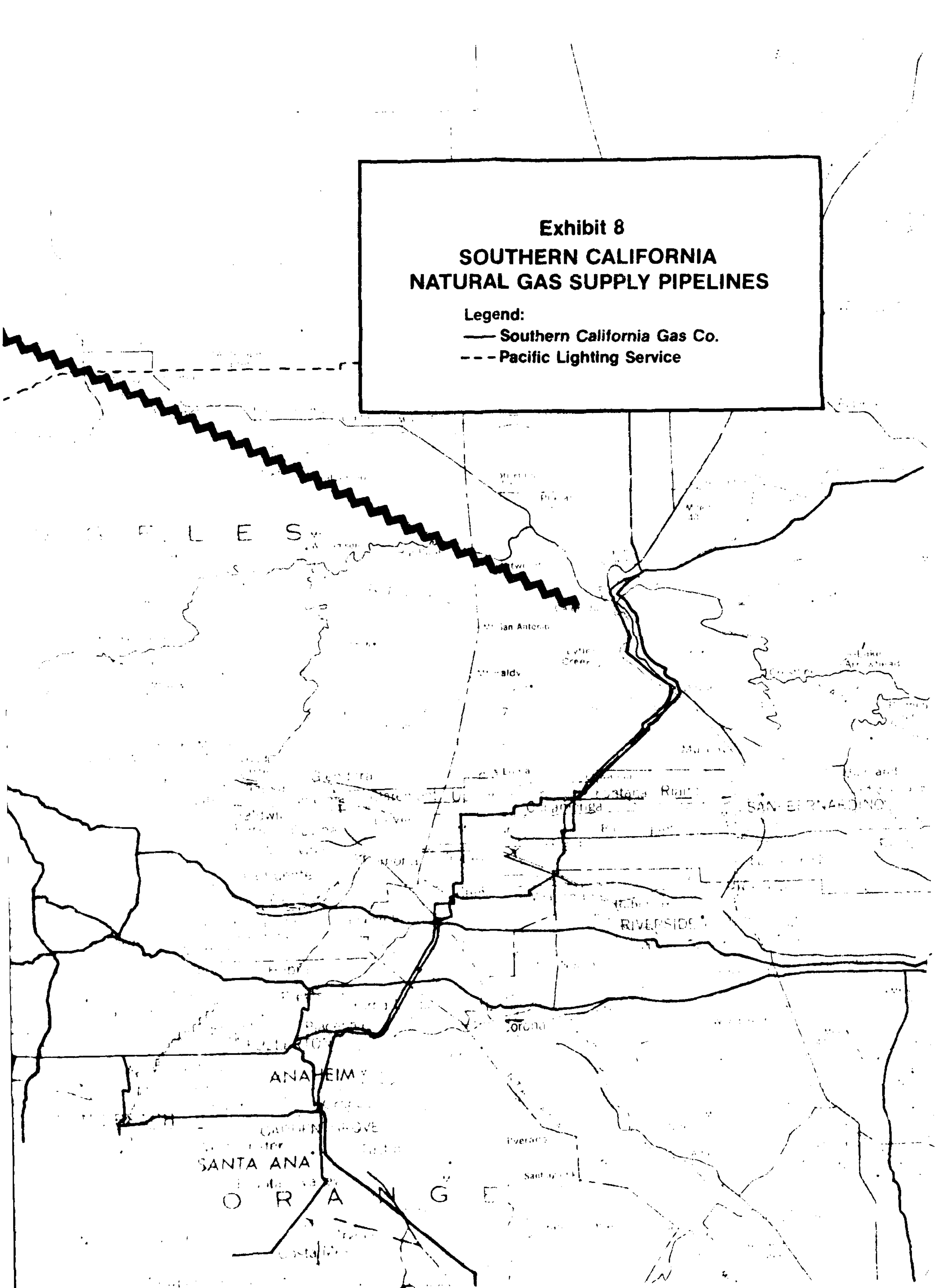


Exhibit 8
SOUTHERN CALIFORNIA NATURAL GAS SUPPLY PIPELINES

Legend:
—— Southern California Gas Co.
- - - Pacific Lighting Service

Berkeley in the East Bay and a line south to the Milpitas Terminal, where service divides between the San Francisco Peninsula and the Santa Clara Valley and points south. The two major lines on the East Bay pass through poor Bayside soil. Of the two major lines on the San Francisco Peninsula, one passes very near the Bay and the other is very close to the San Andreas Fault. There is alternative access to the Bay Area through a branch line that runs north from Livermore to Antioch and thence to Richmond via Martinez. This line also provides service to Marin and Sonoma Counties via branches that cross the Sacramento River at Antioch and Vallejo.

Service is provided to the Los Angeles Area by the Southern California Gas Company (SCG) and by the Pacific Lighting Service (PLS). SCG brings natural gas into the area via five pipelines. Two come from Blythe via Riverside, two come from Needles via Barstow and Ontario and the other supplies California gas from the Central Valley via Tejon Pass and San Fernando. PLS has two major pipelines, one from Needles via Palmdale and San Fernando and the other from the Central Valley via Tejon Pass. The Los Angeles Basin is served by a network of pipelines. SCG generally serves the Los Angeles-San Bernardino corridor, Los Angeles and Orange County. Both companies serve parts of the San Fernando Valley. Except for fault crossings, the Southern California gas lines are generally in areas with good soil. There are exceptions for lines serving coastal communities.

The capacity of a natural gas pipeline depends on its size, the pressure at which it is operated and the number and capacity of its compressor stations. Pipelines operating at 55 atmospheres can be expected to supply natural gas within the following ranges:

Pipe Diameter (inches)	Volume Billion of Cu. Ft./Day*
24	0.2 to 0.4
30	0.3 to 0.6
36	0.5 to 0.9

*At standard conditions.

If one or two compressor stations are lost, capacity is reduced, but substantial delivery is still possible.

PETROLEUM PIPELINES

There is an extensive network of petroleum and petroleum product pipelines throughout California. Most of the petroleum lines connect California producing fields with refineries. Most product lines connect refineries with major distribution terminals. Long distance product lines extend to markets in Arizona and Nevada.

Exhibits 9 and 10 show the locations of the major petroleum and petroleum products pipelines in the San Francisco and Los Angeles areas. There are six refineries in the San Francisco Bay Area with a total refining capacity of 900,000 barrels per day. These refineries are all located on the Bay or on the Sacramento River so that they can receive crude oil from marine terminals. There are also four petroleum pipelines that supply the four largest refineries from oil fields in the Central Valley. These pipelines are routed close together south of the Sacramento River passing through or near Concord, Martinez, Hercules and Richmond. Five of the six refineries supply product pipelines that carry products to bulk terminals. Three of these lines cross the Bay in the vicinity of the San Francisco and Oakland airports. Three are routed along poor soil near the eastern shore of the Bay. Six cross the Hayward Fault. There are also product pipelines to Sacramento and other Central Valley cities.

The pipeline network in the Los Angeles area is very much more complicated due to the existance of active producing fields and a larger population. There are ten refineries in the Los Angeles area with an aggregate refining capacity of 1,100,000 barrels per day. Five of these are located on the water for marine supply and product shipments. All ten refineries are supplied by petroleum pipelines and ship some products by pipeline. Three petroleum pipelines cross the Coast Range near Tejon Pass and follow Interstate 5 to Newhall

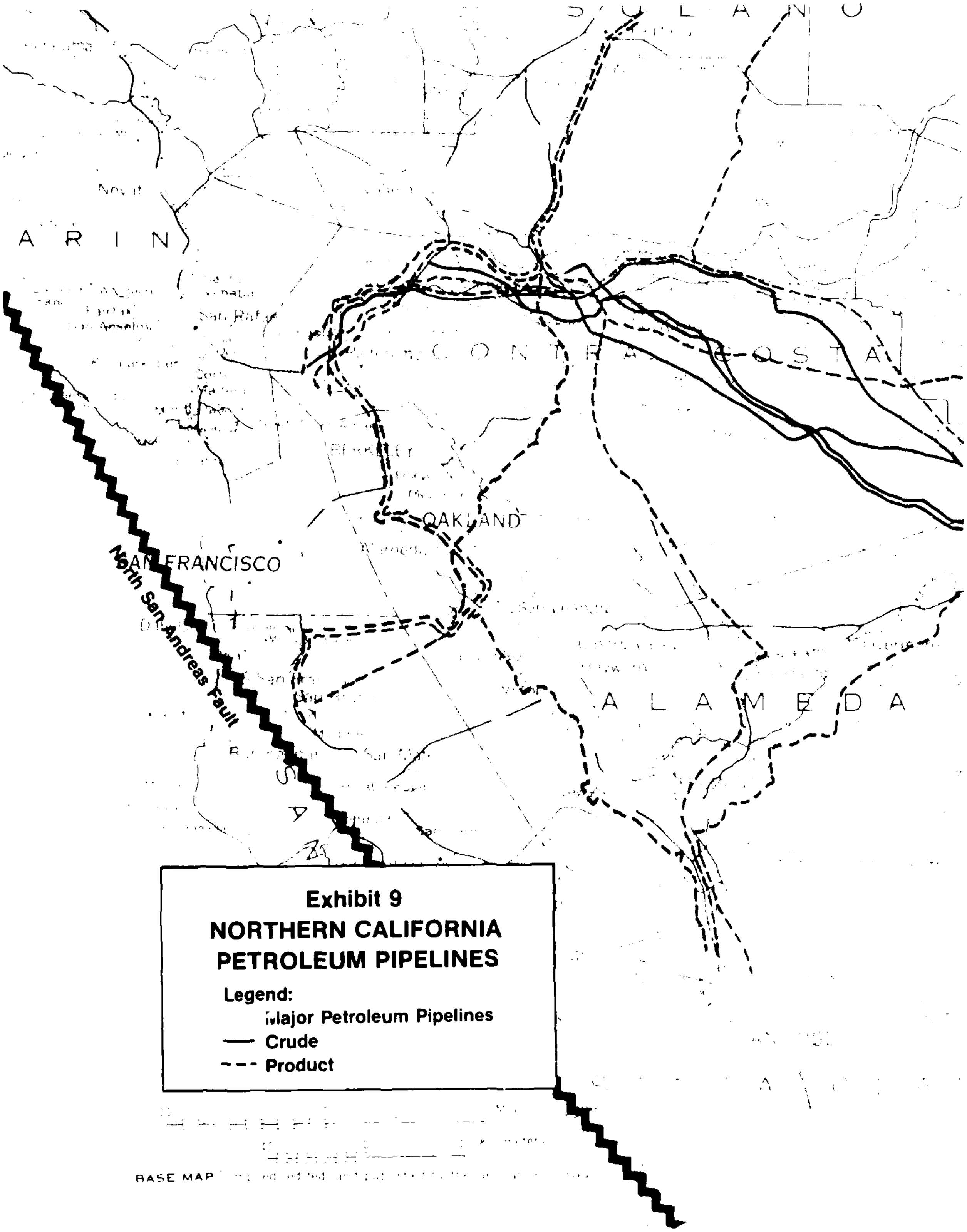
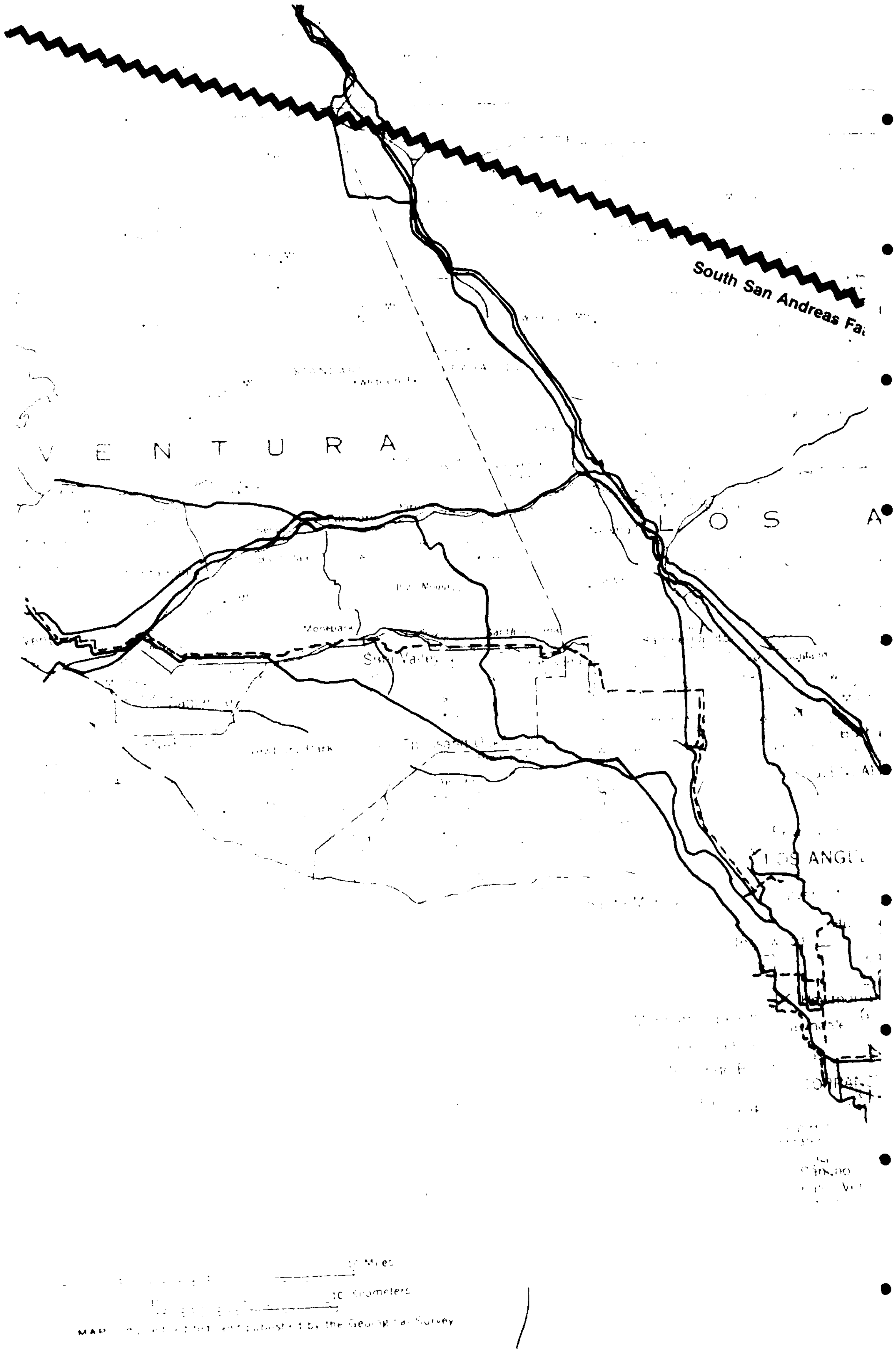


Exhibit 9
NORTHERN CALIFORNIA PETROLEUM PIPELINES

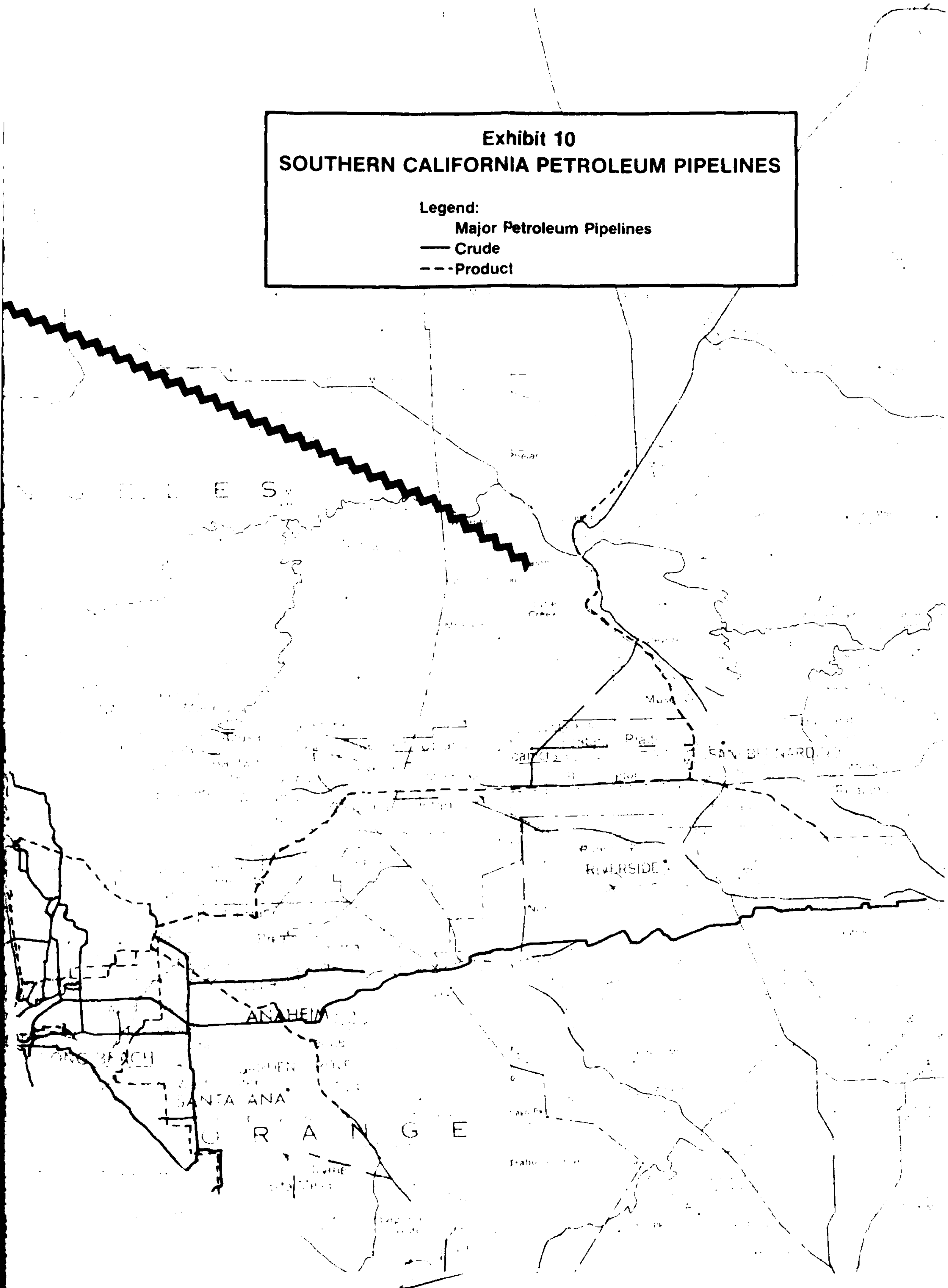
Legend:
Major Petroleum Pipelines
—— Crude
- - - Product



South San Andreas Fa
V E N T U R A
L O S A
Moorpark
LOS ANGE

Exhibit 10
SOUTHERN CALIFORNIA PETROLEUM PIPELINES

Legend:
Major Petroleum Pipelines
—— Crude
- - - Product



near San Fernando) before dispersing to serve their separate refineries. Two pipelines follow the Santa Clara Valley; one joins the other lines at Newhall; and the other crosses the mountains into the San Fernando Valley. Product lines serve major terminals in the Los Angeles area. In addition, there are product lines that extend eastward through San Bernardino to Nevada and Arizona. A product line also serves San Diego.

AIRPORTS

California is served by a number of commercial and military airports that are capable of accommodating the largest jet aircraft. In addition, there are a very large number of general aviation airports and private landing strips that can accommodate military aircraft designed to use unprepared landing sites. The largest of these general aviation airports can accommodate C-141 military [illegible] aircraft which require 5000 ft. runways. The smaller C-130 can land and take off on 3000 ft. runways. Both aircraft have extremely low foot print pressures for operation on poor surfaces.

Exhibit 3 identifies major commercial and military airports and smaller emergency fields. There are three commercial, four [illegible] and seven emergency airports in the San Francisco Bay Area. [illegible] these are located on poor soil that is subject to earthquake [illegible]. There are six commercial, six military and at [illegible] emergency airports in the Los Angeles area. Most of [illegible] soil and therefore are likely to survive the [illegible].

[illegible] FACILITIES

[illegible] major port facilities both on the coast and on [illegible] shows the location of commercial and military [illegible] waterways by which they have access to the Pacific [illegible] capable of serving commercial ships are included.

All ports in the San Francisco Bay area are accessible only through the Golden Gate. Major ports in San Francisco and Oakland also require ships to pass under the Bay Bridge. In addition, there are port facilities in Alameda, Redwood City and Richmond. Bulk terminals are located at Richmond, San Pablo, Rodeo, Crocket and Benicia. Tugs can be serviced at other facilities. Sacramento and Stockton have substantial ports that require ships to navigate considerable distances up the Sacramento and San Joaquin Rivers. Both estuaries are subject to closing by falling bridges. Military facilities at Alameda, Oakland, Richmond and Port Chicago can handle emergency cargo.

Commercial port facilities in the Los Angeles area are concentrated at the adjacent ports of Los Angeles and Long Beach. There are additional facilities at Port Hueneme. Military facilities are available at Terminal Island, Seal Beach, and at Port Hueneme. There are no waterways to be concerned with in the Los Angeles area, although access to some facilities at the Ports of Los Angeles and Long Beach can be prevented by fallen bridges.

III. ISOSEISMAL MAPS

Isoseismal maps were prepared for each of the four example earthquakes using a technique developed by Dr. J. F. Evernden of the U.S. Geological Survey. Evernden has hypothesized that, for California earthquakes, intensity, as expressed in the Rossi-Forel (R-F) scale, can be related to maximum length of the fault break, depth of focus, distance from fault, shock attenuation and soil conditions. Using his technique, Evernden has estimated earthquake intensities for several historical California earthquakes with good success.*

Evernden developed two different computer programs to estimate earthquake intensities. The first, which was used to prepare isoseismal maps, estimates earthquake intensities for most of the state of California using digitized geological data taken from the Geologic Map of California (Olaf P. Jenkins edition). Geological data were available on a 1/2 by 1/2 minute grid for the coastal and central portions of the state. For each square of the grid, the geological data were grouped into the 10 seismic response units listed in Exhibit 11. A single value was selected for each square based on the most prevalent known material in the square. Given a set of earthquake descriptors the computer program calculates the earthquake intensity for each square and plots the estimated intensity at a scale of 1:250,000. These data can be transferred directly to maps of this scale. Exhibit 12 illustrates the plots that are prepared.

*Evernden, J. F., W. M. Kabler and G. D. Clow, Seismic Intensities of Earthquakes of Conterminous United States--Their Prediction and Interpretation, U.S.G.S., Menlo Park: 1981.

EXHIBIT 11

SEISMIC RESPONSE UNITS

Geologic map units	Ground-condition unit
Granitic and metamorphic rocks	A
Paleozoic sedimentary rocks	B
Early Mesozoic sedimentary rocks	C
Cretaceous through Eocene sedimentary rocks	D
Undivided Tertiary sedimentary rocks	E
Oligocene through middle Pliocene sedimentary rocks	F
"Plio-Pleistocene" sedimentary rocks	G
Tertiary volcanic rocks	H
Quaternary volcanic rocks	I
Quaternary sedimentary rocks	J

Source: Evernden et al., op cit.

The computer program estimates all alluvial soil (Condition J in Exhibit 11) as being water saturated. In practice, the water table varies. Evidence indicates that earthquake intensities are lower for dry soil than for saturated soil. In particular, there appears to be a pronounced reduction in intensity if the water table is 10 meters or more below the surface of the earth. This situation was incorporated in the isoseismal maps by adopting estimates of potential ground failure from the work of the state Task Force*, and of others**.

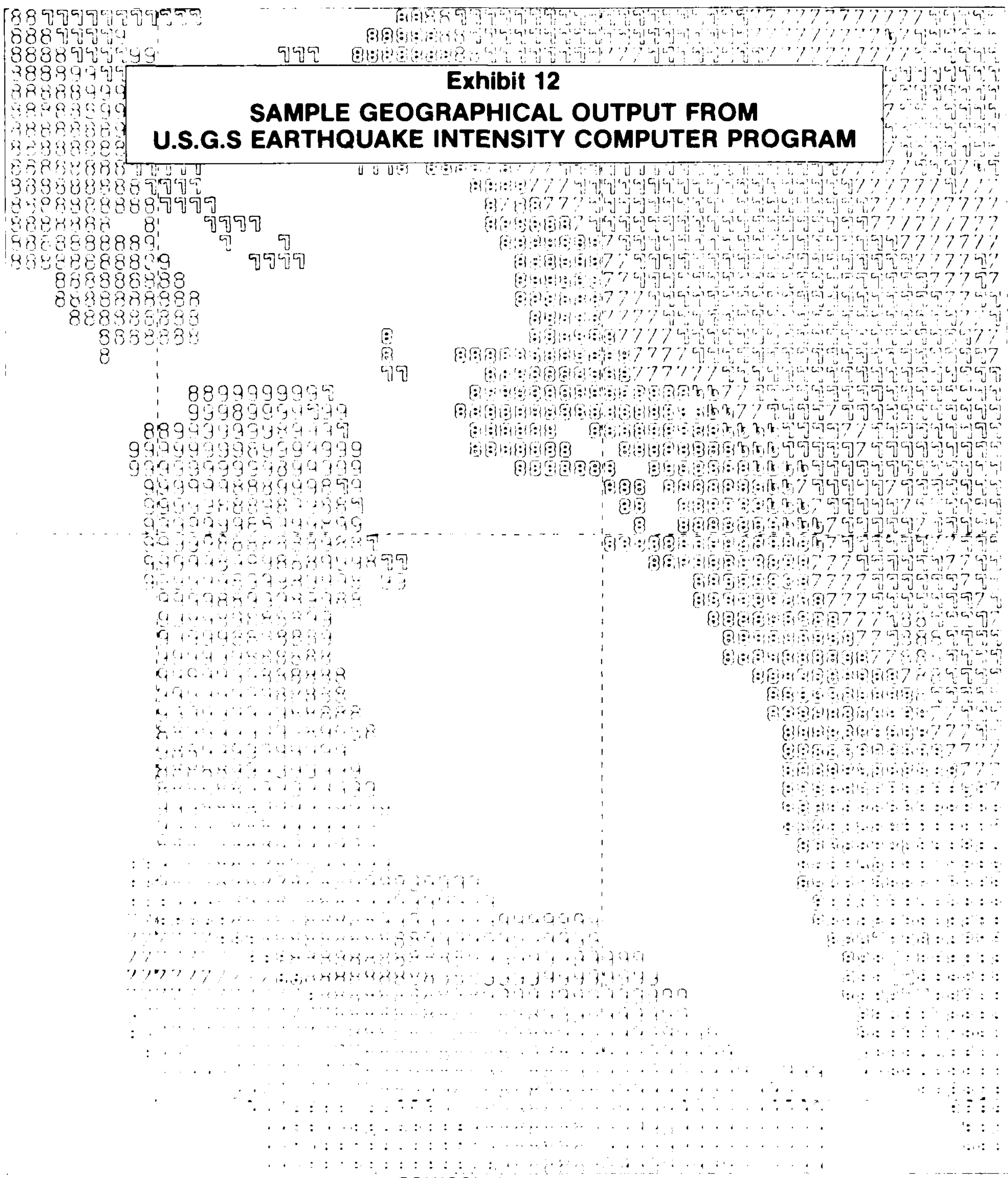
The second of Evernden's computer programs performs essentially the same calculations, but calculates earthquake intensities

*Davis, J. E., et al., op cit.

**Yound et al., Professional Paper 941-A, U.S.G.S., Menlo Park: 1975.

Exhibit 12

SAMPLE GEOGRAPHICAL OUTPUT FROM U.S.G.S EARTHQUAKE INTENSITY COMPUTER PROGRAM



POLYCONIC PROJECTION

SCALE 1:250,000

These intensities are corrected for ground condition in the manner described by J F Evernden. 1975, BSSA, 65. 1287-1313. In this map depth to the water table is assumed to be 10 meters or greater. Thus intensities on alluvium are one unit less than those calculated for saturated alluvium.

Single stroke characters indicate intensities in the lower half of an intensity band while hollow characters indicate intensities in the upper half. For example, intensities 5.50-5.99 are indicated by the character 6. Intensities 6.00-6.50 are indicated by the character 6.

for any set of locational data. This program was used to estimate the potential earthquake intensity for each of the transportation resources. Latitude and longitude (to 0.1 minute) were extracted from the data files or estimated by plotting resources on large scale maps. The computer program estimated an earthquake intensity for each point based on alluvial soil. Where more accurate soil data were available, these estimates were adjusted.

METHOD USED TO PREPARE ISOSEISMAL MAPS

The U.S.G.S. earthquake intensity plots were the primary data source for the isoseismal maps. Overlays were traced over each plot to determine the boundaries between areas expected to experience different earthquake intensities, beginning with VII Rossi-Forel, the intensity below which transportation facilities are not expected to be damaged. Points on the boundaries between intensity regions were joined with reasonably smooth curves. Some of the intensity areas are very small, comprising a single 1/2 minute by 1/2 minute square; others are quite large. The overlays were then reduced in scale to 1:500,000 scale and traced on the U.S.G.S maps of the same scale that were selected to display geographical results. These results were carefully examined for accuracy, and adjusted when necessary.

To conform with more common engineering practice, the maps were converted from Rossi-Forel to the Modified Mercalli intensity scale. Both scales are based on observed earthquake effects. Because it was proposed in 1883, the Rossi-Forel (R-F) scale does not include damage to modern reinforced concrete and steel structures. The Modified Mercalli (MM), first proposed in 1931, includes damage to modern structures, has a broader range of destruction and is popular with structural engineers. Exhibit 13 lists one comparison between Rossi-Forel and Modified Mercalli intensities. For purposes of preparing the isoseismal maps,

only two boundaries were of interest:

Modified Mercalli	Rossi-Forel
VII	VIII
VIII	IX

This conversion does not strictly conform to those proposed by Neumann* or Evernden**, but in view of the uncertainties about soil data and the use of 1/2 minute grids, it gives a reasonable approximation.

The product of this work is a map that identifies the areas of greatest earthquake intensity for each example earthquake. The coverage of each map is restricted to the area likely to experience a shock of MM VII or greater.

NORTH SAN ANDREAS FAULT

An 8.3 magnitude earthquake on the north San Andreas Fault would produce substantial shocks over a wide area that extends along the 400 km of fault break from Shelter Cover to San Juan Bautista. Most of the damage would be concentrated in the heavily populated area between Petaluma on the north and Hollister on the south. Exhibit 14 illustrates the areas within this populated region that are likely to be subjected to Modified Mercalli shocks of VII and VIII. Although one cannot dismiss the possibility of shocks with intensity IX or greater, these are likely to be confined to small areas with unique soil characteristics. They are too small to be included within the geological grain size of the 1/2 by 1/2 minute grid.

As illustrated in Exhibit 14, the San Andreas Fault is very close to the coast until it moves inland at Daly City just south of San Francisco. From Daly City, the Fault continues southeast, near the crest of the Santa Cruz Mountains, passing under the San

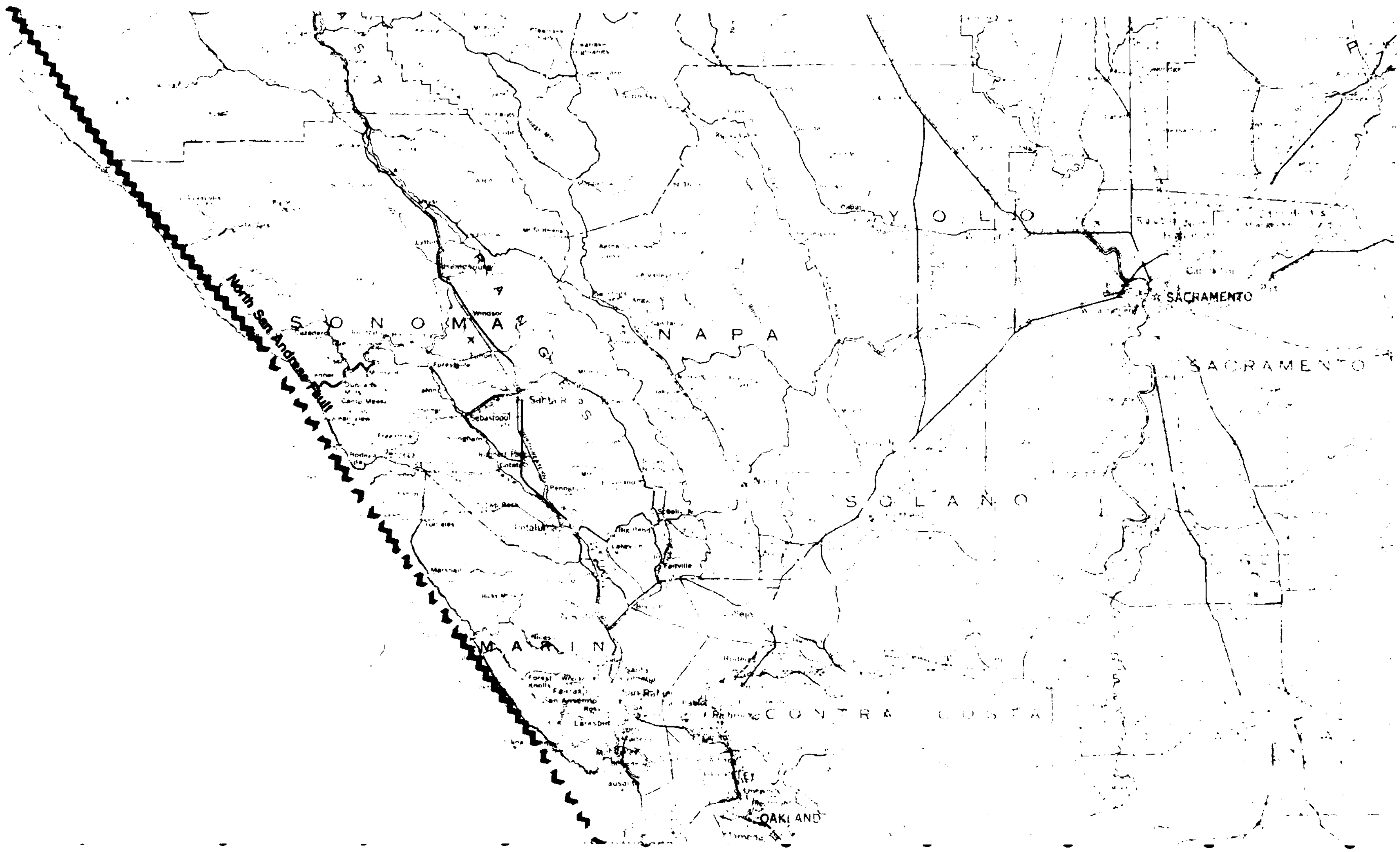
* Neumann, F., "United States Earthquakes--1929", Ser. 533, U.S. Coast and Geodetic Surveys, Washington: 1931

**Evernden, J.F., W.M. Kohler and G.D. Clow, Seismic Intensities of Earthquakes of Conterminous United States--Their Prediction and Interpretation, Geological Survey Professional Paper 1223, U.S. Government Printing Office, Washington: 1981

EXHIBIT 13

COMPARISON BETWEEN ROSSI-FOREL AND MODIFIED MERCALLI EARTHQUAKE INTENSITIES

Rossi-Forel Intensity	Modified Mercalli Intensity
I	I
II	II
III	III
IV	III-IV
V	IV-V
VI	V-VI
VII	VI
VIII	VII
IX	VIII
X	IX-X
	XI
	XII


SACRAMENTO
SACRAMENTO
YOLO
SOLANO
NAPA
SONOMA
MARIN
CONTRA COSTA
OAKLAND
North San Andreas Fault
Santa Rosa
Sebastopol
Petaluma
Windsor

1

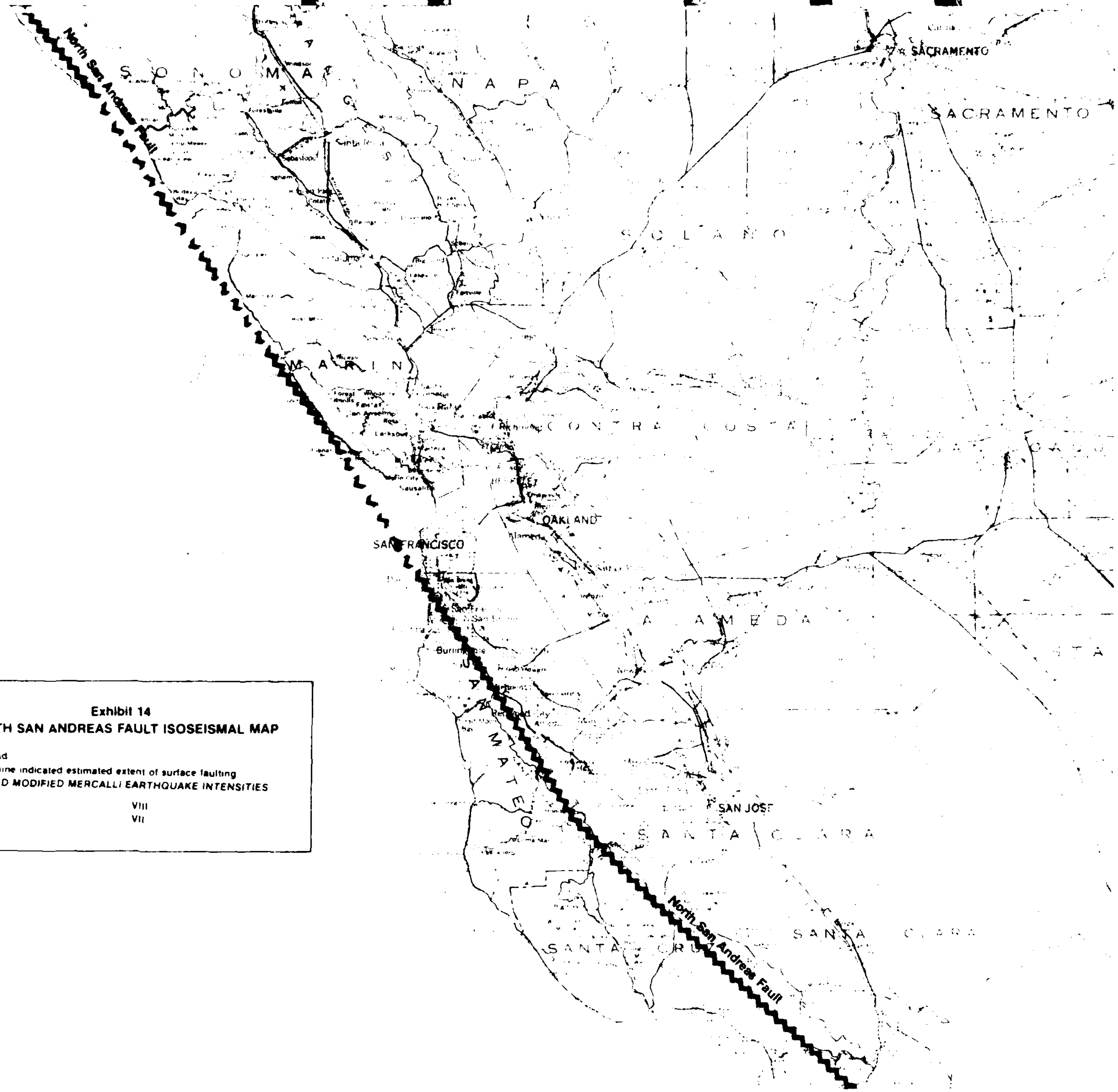


Exhibit 14
NORTH SAN ANDREAS FAULT ISOSEISMAL MAP

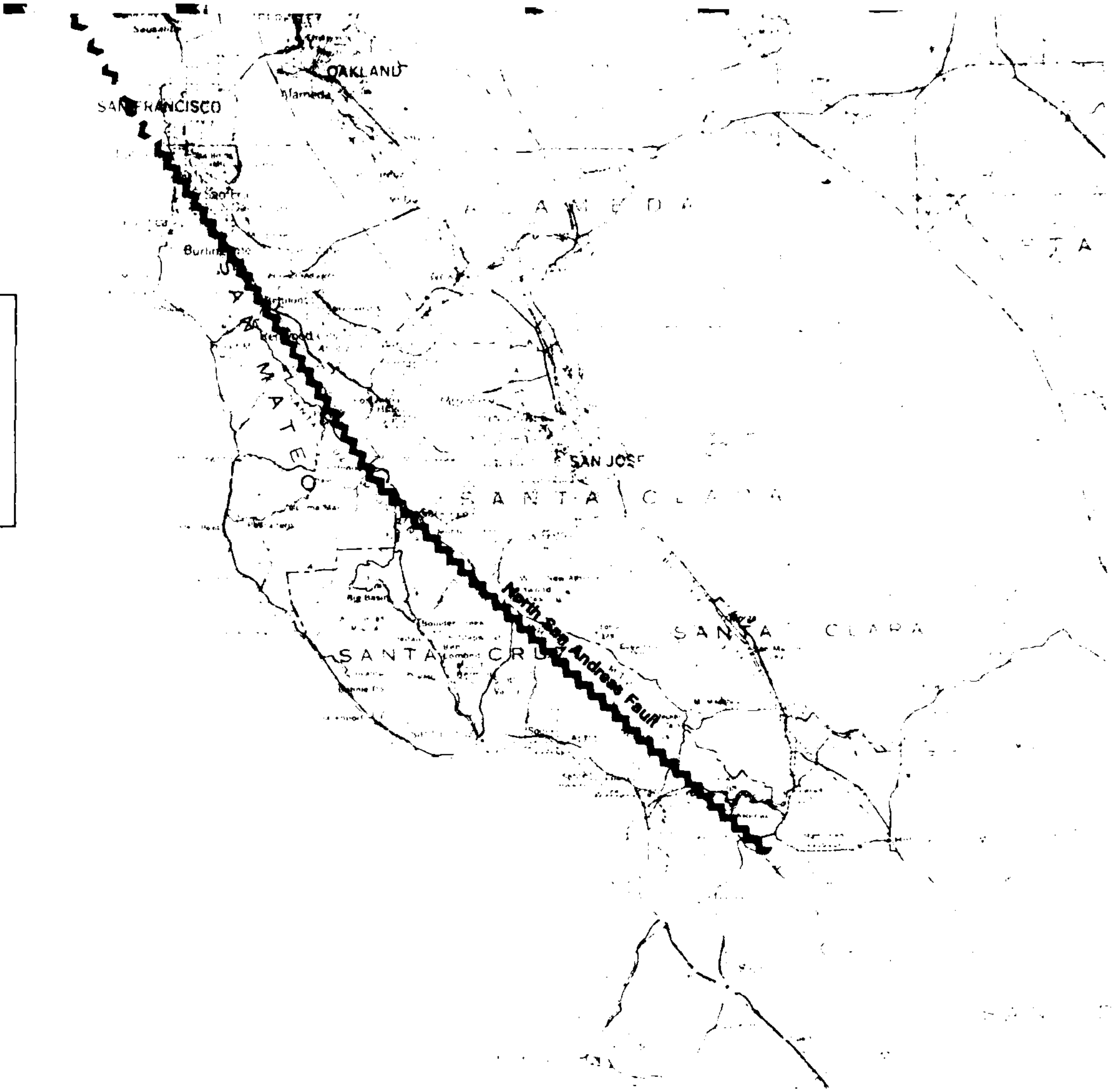
Legend
Fault line indicated estimated extent of surface faulting
ESTIMATED MODIFIED MERCALLI EARTHQUAKE INTENSITIES

VIII
VII

Exhibit 14
NORTH SAN ANDREAS FAULT ISOSEISMAL MAP

Legend:
Fault line indicated estimated extent of surface faulting
ESTIMATED MODIFIED MERCALLI EARTHQUAKE INTENSITIES

VIII
VII



Andreas and Crystal Springs reservoirs. The postulated fault break ends on the eastern slope of the Galilan Mountains near San Juan Bautista.

The areas of greatest earthquake intensity lie on either side of the fault for a distance that does not exceed 45 km. The intensities along the fault line vary between MM VII and VIII depending on the geologic formation. Both of these earthquake intensities are capable of inflicting damage on transportation facilities as suggested by the following definitions:

MM VII Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motor cars.

MM VIII Damage slight in specially designed structures; considerable in ordinary substantial buildings, with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving motor cars disturbed.*

Greater intensities would, of course, inflict greater damage. Areas with intensity VII include the reservoir beds with alluvial soil over rock and pockets of alluvial soil elsewhere. The largest areas likely to be subjected to intensity VII are the alluvial deposits around the San Francisco Bay, in Santa Clara Valley and on the coast of Monterey Bay from Soquel (east of Santa Cruz) southeast to a point just beyond Watsonville.

Problems in the San Francisco Bay area are compounded by the large amount of filled land, made from unconsolidated material over Bay mud. Damage in the 1906 earthquake was heavy on land

*Wood, H.O. and F. Neumann, "Modified Mercalli Intensity Scale of 1931," Bulletin of Seismic Society of America, 21:277-283.

fills in the Mission Valley of San Francisco and along the water front. After 75 years of additional compaction, this soil should perform better in future earthquakes. Even new fills on good soil can be expected to perform well as illustrated by the 1957 earthquake centered in Daly City. However, extensive ground failure can be expected in new communities like Foster City, Redwood Shores and developments adjacent to Alameda and other East Bay cities. These failures may take the form of liquifaction, slumping or settling. Waterfront land also tends to suffer greater shocks because of water saturation.

HAYWARD FAULT

A 7.5 magnitude earthquake on the Hayward fault would produce a damage pattern in the San Francisco Bay area that resembles damage from a shock on the San Andreas fault. In both instances there would be widespread damage on alluvial land on both sides of the Bay and in the Santa Clara Valley.

As illustrated by the seismal map of Exhibit 15, damage from a Hayward fault earthquake would be much more localized than a San Andreas fault earthquake. The Hayward shock would produce more intense damage in the East Bay, heavy damage on the east slope of the Oakland hills and severe damage in the Amador Valley around Livermore and in the Concord-Walnut Creek area. Surface faulting could be expected to extend from Pinole Point to Mission San Jose, creating serious damage to pipelines, highways and railways. Fault slippage could be as great as 2 meters. There would also be damage on the east slope of the Diablo Range near Tracy and in the San Joaquin River delta.

Away from the alluvial planes, damage on the west side of the Bay would be moderate. Alluvial soils along the coast and in the Santa Cruz Mountains may experience intensities as high as MM VII. However, heavy damage is not likely to occur as far north as Petaluma or as far south as Salinas.

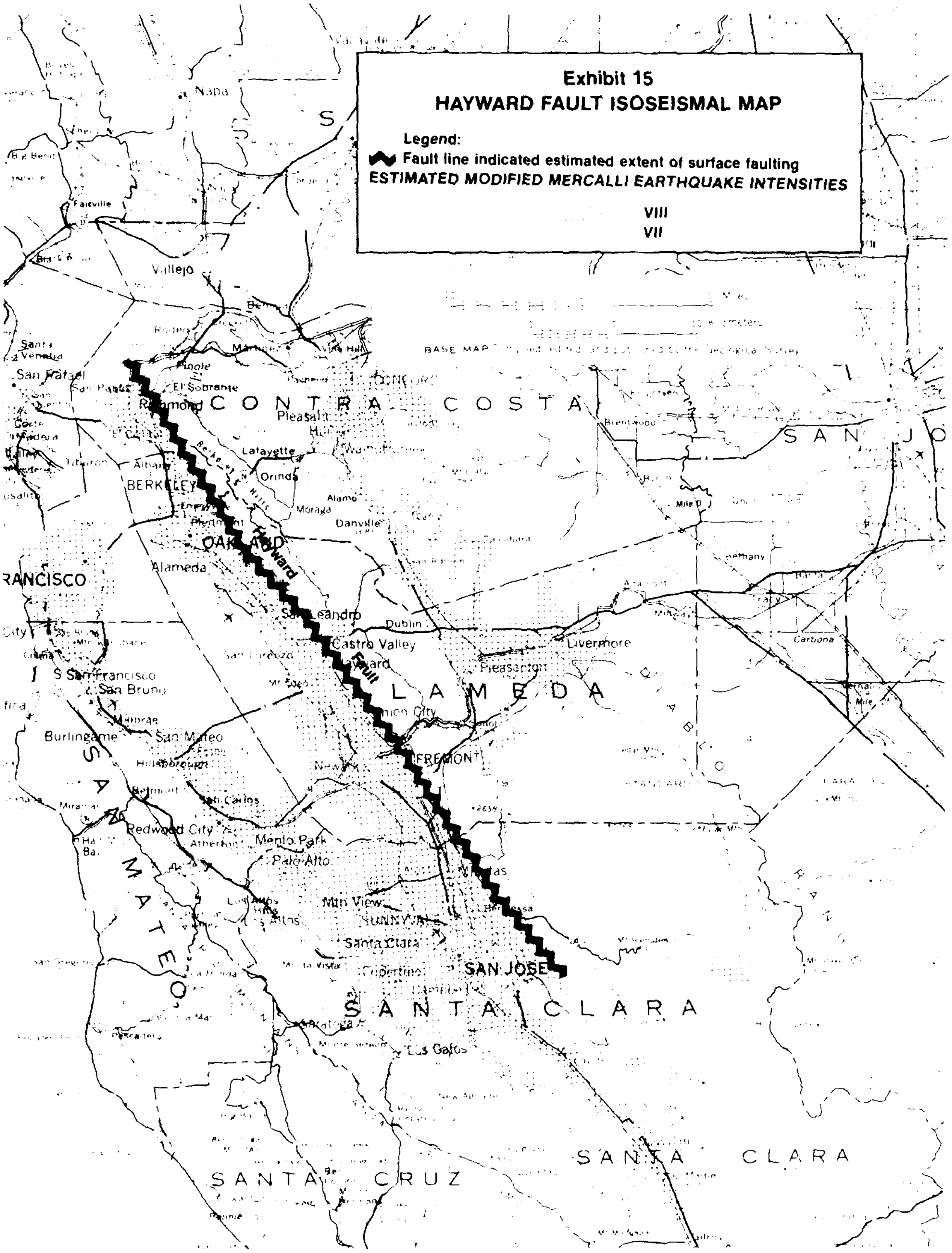


Exhibit 15
HAYWARD FAULT ISOSEISMAL MAP
Legend:
Fault line indicated estimated extent of surface faulting
ESTIMATED MODIFIED MERCALLI EARTHQUAKE INTENSITIES
VIII
VII
Napa
Vallejo
San Rafael
El Sobrante
Richmond
CONTRA COSTA
Pleasant Hill
Lafayette
Orinda
Albany
BERKELEY
Moraga
Alamo
Danville
Berkeley Hills
OAKLAND
Hayward
Alameda
RANCISCO
San Leandro
Dublin
Castro Valley
Fault
Livermore
Pleasanton
ALAMEDA
S San Francisco
San Bruno
Burlingame
San Mateo
Union City
FREMONT
Newark
Belmont
San Carlos
Redwood City
Menlo Park
Palo Alto
SAN MATEO
Milpitas
Mtn View
SUNNYVALE
Santa Clara
Cupertino
SAN JOSE
SANTA CLARA
Los Gatos
Carbona
SAN JO
SANTA CRUZ
SANTA CLARA

SOUTH SAN ANDREAS FAULT

An 8.3 magnitude earthquake on the South San Andreas fault would cause intense damage over a wide area. Surface faulting would be expected to extend for 320 km from Cholame (Notheast of San Luis Obispo) south easterly to Cajon Junction (Northwest of San Bernardino). As illustrated in Exhibit 16 there would be areas of intense damage (MM VIII) on both sides of the fault. These areas are roughly divided by the east-west range of Tehachapi Mountains on which earthquake intensities would be less than MM VII. In the north west areas of high intensity would center on the Carrizo Plain between the Tremblor and Caliente mountain ranges. In the northeast, intense damage would occur in the south end of the San Joaquin Valley near Taft and McKittrick. Heavy damage would extend to Bakersfield and the foothills of the Sierra Nevada. Damage west of the Sierra Madre would be light. Thus San Luis Obispo, Santa Maria and Santa Barbara would be only lightly damaged. In the south, there would be intense damage northeast of the San Gabriel Mountains in Antelope Valley near Lancaster and Palmdale. Heavy damage would extend toward but not to Barstow and Mojave. None of the areas subjected to intense shaking are heavily populated.

In the Los Angeles Basin, there would be heavy (MM VII) damage in San Bernardino and westward (south of the San Gabriel Mountains) to Pasadena and northwest to San Fernando. Intensities in the densely populated areas would be MM VI or less.

NEWPORT-INGLEWOOD FAULT

A [illegible] magnitude earthquake on the Newport-Inglewood fault would produce heavy damage (MM VII) throughout the Los Angeles [illegible] (Exhibit 17). Surface faulting is likely to extend from [illegible] southeast through Gardenia, Signal Hill and Huntington [illegible] Newport Beach. Although no underwater trace has been

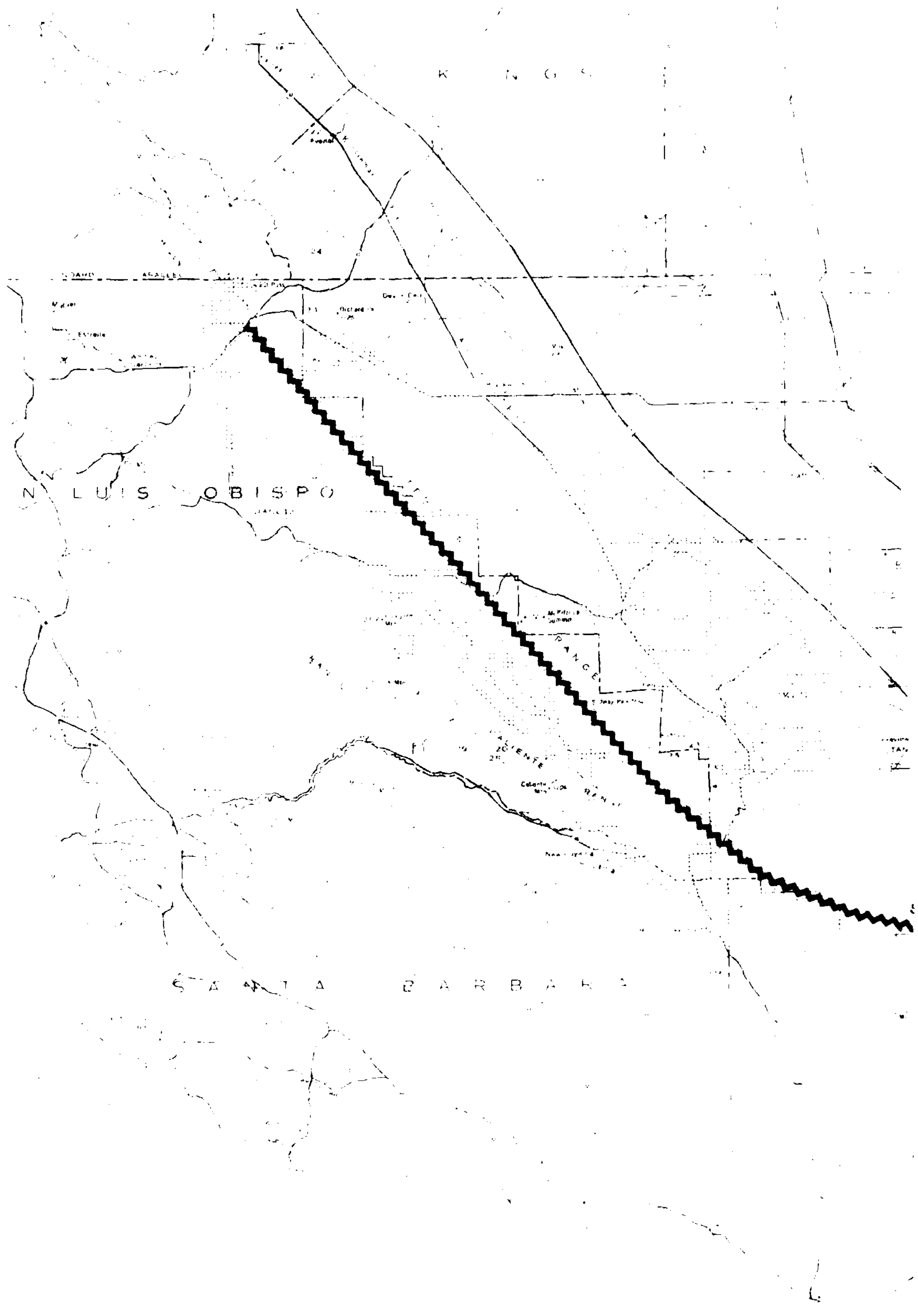

LUIS OBISPO
SANTA

Exhibit 16
SOUTH SAN ANDREAS FAULT ISOSEISMAL MAP

Legend:
Fault line indicated estimated extent of surface faulting
ESTIMATED MODIFIED MERCALLI EARTHQUAKE INTENSITIES

VIII
VII

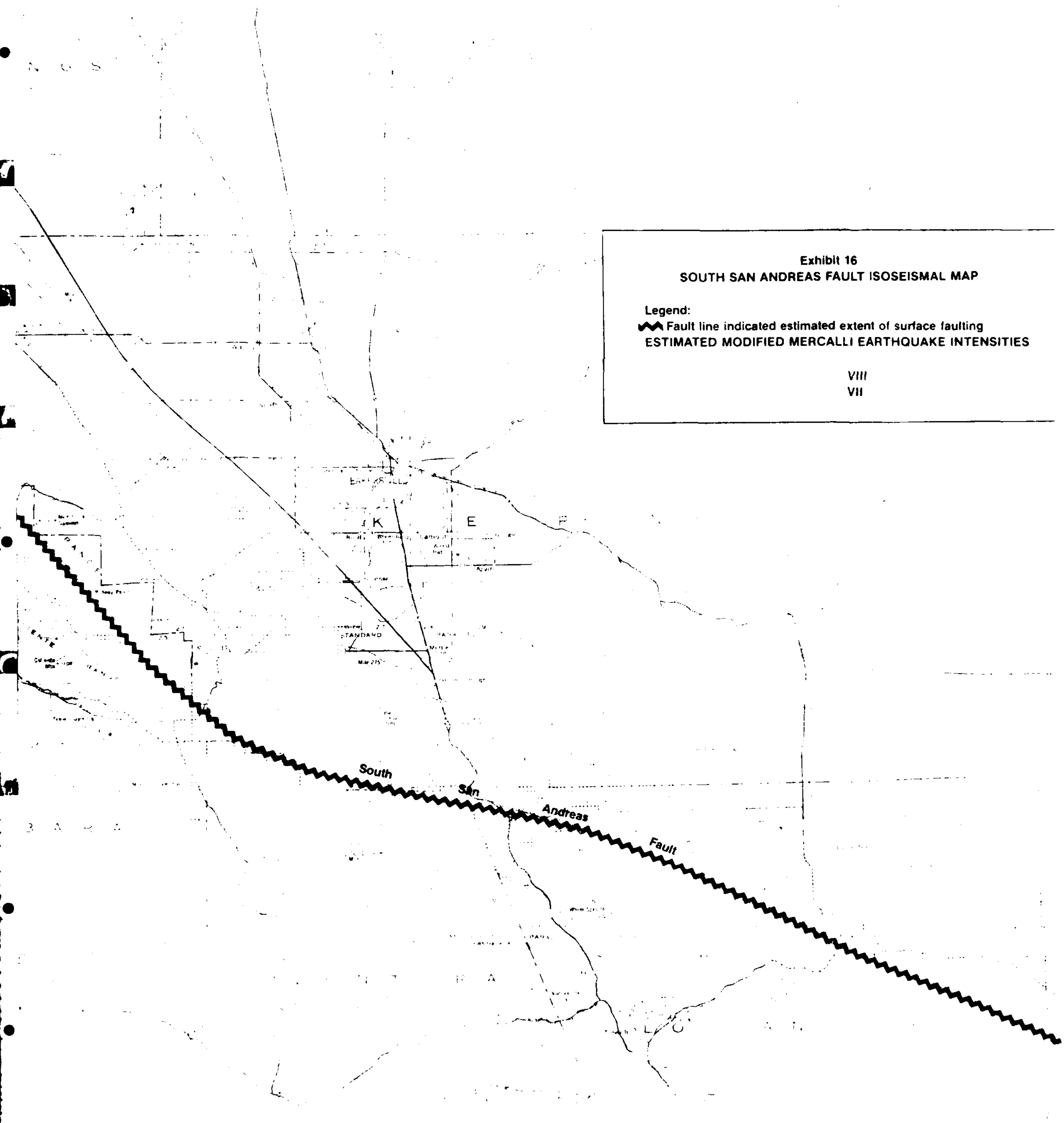
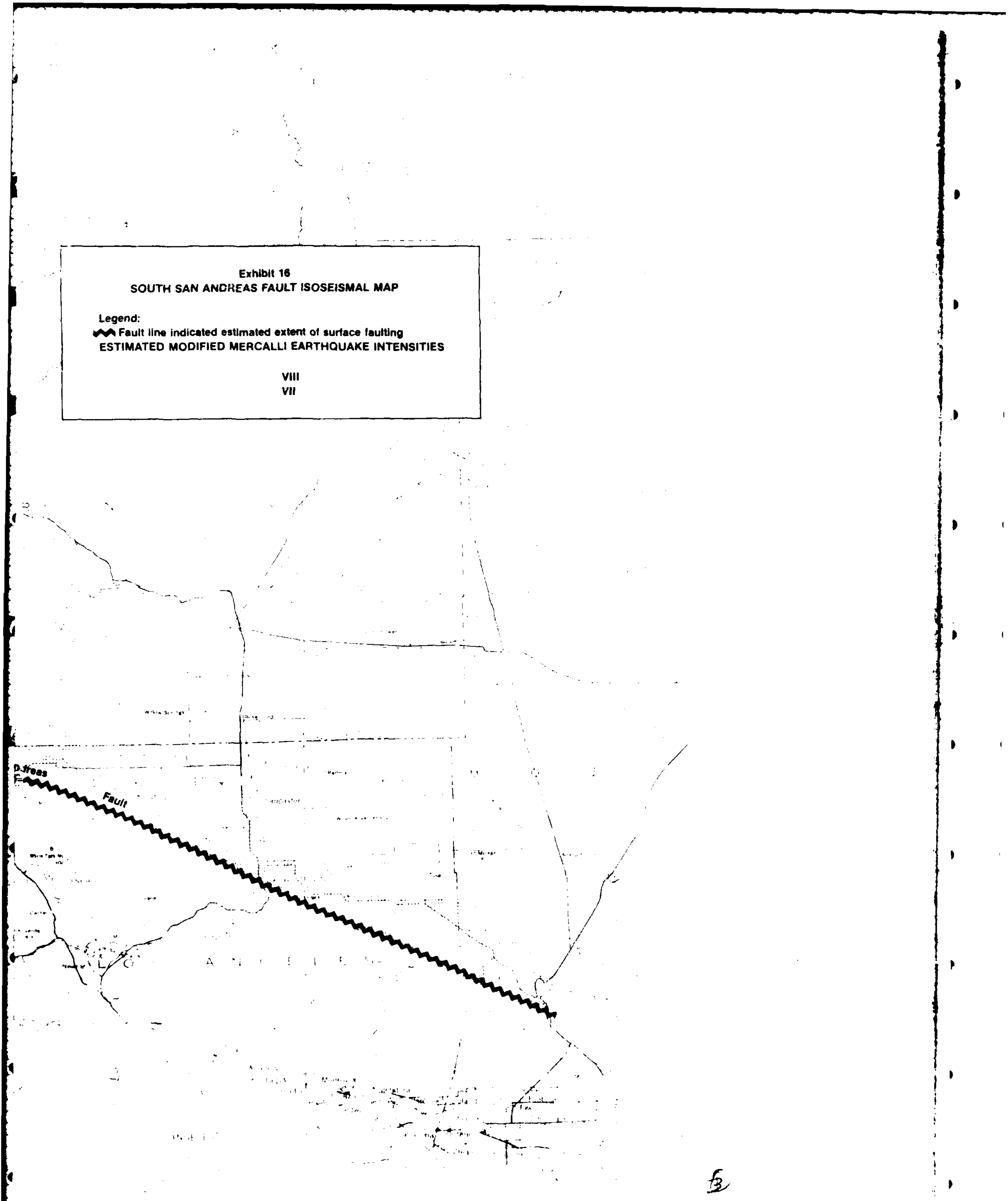


Exhibit 16
SOUTH SAN ANDREAS FAULT ISOSEISMAL MAP

Legend:
Fault line indicated estimated extent of surface faulting
ESTIMATED MODIFIED MERCALLI EARTHQUAKE INTENSITIES

VIII
VII



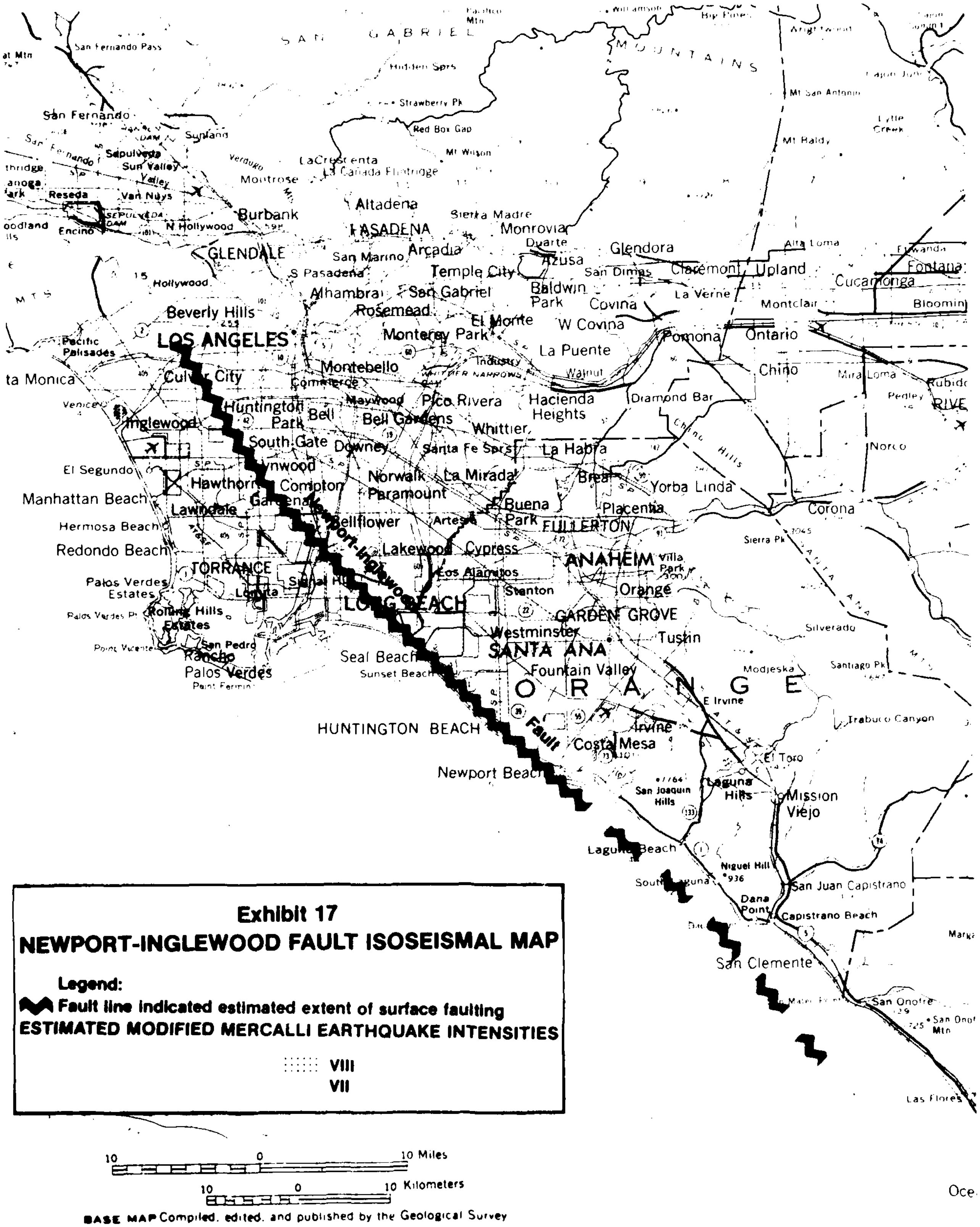


Exhibit 17

NEWPORT-INGLEWOOD FAULT ISOSEISMAL MAP

Legend:

Fault line indicated estimated extent of surface faulting

ESTIMATED MODIFIED MERCALLI EARTHQUAKE INTENSITIES

VIII

VII

10 0 10 Miles

10 0 10 Kilometers

BASE MAP Compiled, edited, and published by the Geological Survey

identified, the fault may extend parallel to the coast under the Pacific Ocean past San Clemente to San Mateo Point.

Although intense damage (MM VIII) would be limited to a narrow strip adjacent to the fault, heavy damage (MM VII) can be expected throughout most of the population area. The damaged area would extend to the San Fernando Valley on the north. It would be bounded by the ocean on the southwest and include Pasadena, Anaheim, and Mission Viejo, extending South to Oceanside.

IV. 8.3 MAGNITUDE EARTHQUAKE ON THE NORTH SAN ANDREAS FAULT

The analysis of the transportation damage that might be inflicted by an 8.3 magnitude earthquake on the northern part of the San Andreas fault was conducted mode by mode, following the procedures illustrated in Exhibit 2. The process treats transportation modes by route segment or by independent facility, using the structure described in Chapter II. The analytical sequence for each mode begins with a damage assessment followed by a post earthquake capability assessment. The final step is an integrated, multi-modal analysis for the area affected by the earthquake.

HIGHWAY TRANSPORTATION

An earthquake on the North San Andreas Fault would inflict substantial damage on highway route segments in the San Francisco Bay area and on the north coast of California. Two types of damage were explored: (1) structural damage to bridges and tunnels and (2) ground failures of roadbeds.

Structural Damage

Using the U.S.G.S. computer program, earthquake intensities were estimated for each of the 1239 highway structures that were identified by Caltrans as being especially vulnerable to earthquake damage. Intensities were expressed in terms of the Rossi-Forel scale, and calculated for saturated alluvial soil. For some structures, these intensities were modified to reflect actual ground conditions at the site. Of the 1239 highway bridges in the

data base, 367 would be subjected to an intensity of R-F VIII or greater.

Damage that the estimated earthquake intensity would inflict on each structure was estimated in terms of its structural characteristics. The probability that an earthquake of R-F VIII or greater would render a structure unusable was estimated by Mr. K. V. Steinbrugge, and is listed in Exhibit 18. Four categories of structures were examined:

- Culverts or tunnels--box, pipe and arch structures that are typically covered by sufficient fill so that failure does not often render the roadway unusable. When it does, repairs can usually be made quickly;
- Bridges with continuous girders or decks that have sufficient structural continuity to avoid collapse even if piers or columns are shifted or fail;
- Arch bridges that normally have abutments on rock which is structurally sound; and
- Simple spans, including simple span truss bridges, that are the most vulnerable of all; shifting of piers or abutments can cause collapse.

Three types of damage were considered: settlement, repairable damage and serious damage. Settlement is earth failure at abutments or approaches. Settlement can impair or stop traffic, but it can be quickly corrected, at least on a temporary basis. Repairable damage includes shifting of abutments, broken wing walls, pounding at structural separations and damage at girder seats. It weakens the structure but does not lead to collapse. Repairable damage to bridges crossing major highways does not affect the traffic carrying capability of the major highway. Bridges suffering repairable damage can be shored up in a matter of a few days or weeks and thereafter carry traffic but not fully loaded trucks. Serious damage occurs when one or more spans fall. The highway using the bridge is rendered unusable and the highway under the bridge is blocked. Fallen spans can be removed in a few weeks to

EXHIBIT 18

EARTHQUAKE DAMAGE TO HIGHWAY STRUCTURES

Rossi-Forel Intensity	Damage Category	Probability of Non-Functional Structure by Type: Culverts, Tunnels; Box, Pipe and Arch	Bridges with Continuous Girders or Decks	Arch Bridges; Concrete, Steel	Simple Spans
VIII	Serious	0	1	1	3
	Repairable	0	2	2	5
	Settlement	0	5	2	10
IX	Serious	1	2	3	5
	Repairable	3	5	6	10
	Settlement	5	12	6	25

Source: K. V. Steinbrugge

restore traffic on the highway under the bridge; but full bridge restoration is likely to take months.

Bridges subjected to an earthquake intensity of R-F VIII or greater were identified by route and route segment. Bridges carrying the route segment were separated from those crossing it. A single probability, Ps, was calculated that each route segment would be usable after the earthquake:

$$Ps = \left(\prod_{i=1}^{n} (1-p_i)\right) \left(\prod_{j=1}^{m} (1-p_j)\right)$$

where: p_i is the probability that a structure carrying the segment would suffer repairable damage, and p_j is the probability that a structure crossing the structure would suffer serious damage. Exhibit 19 lists the probabilities of survival calculated for the 46 route segments that contain or are crossed by one or more structures that would be subjected to shocks of R-F VIII or more.

The analysis began by identifying all bridges and bridge characteristics for each route segment. The number of spans comprising each bridge and its approaches were noted. The entire bridge was

EXHIBIT 19

PROBABILITY THAT HIGHWAY ROUTE SEGMENTS WOULD
SURVIVE NORTH SAN ANDREAS FAULT EARTHQUAKE

Route Segment					Bridges Subjected to Damaging Shock			
						Spans		Prob.
Hwy No.	From Highway		To Highway		Bridges	Under Hwy	Over Hwy	None Damaged
1	101	(Leggett)	101	(Mill Valley)	10	141	8	0
1	101	(Mill Valley)	280	(Daly City)	4	41	4	0.05
1	280	(Daly City)	92	(Belmont)	6	11	2	0.57
1	92	(Belmont)	17	(San Jose)	9	14	0	0.48
1	17	(San Jose)	129	(Gilroy)	7	44	16	0.04
1	129	(Gilroy)	156	(Castroville)	4	12	22	0.48
17	101	(San Rafael)	80	(Richmond)	5	458	60	0
17	80	(Oakland)	238	(San Lorenzo)	18	362	46	0
17	238	(San Lorenzo)	84	(Fremont)	8	14	36	0.36
17	84	(Fremont)	237	(Milpitas)	4	5	12	0.70
17	237	(Milpitas)	101	(San Jose)	5	12	18	0.48
17	101	(San Jose)	1	(Santa Cruz)	7	40	34	0.03
24	580	(Oakland)	680	(Walnut Creek)	18	214	28	0.01
37	101	(Novato)	12	(Vallejo)	1	57	0	0.01
80	101	(San Francisco)	17	(Oakland)	4	614	4	0
80	17	(Oakland)	17	(Richmond)	4	19	36	0.37
80	17	Richmond	4	(Pinole)	2	4	11	0.78
80	4	(Pinole)	680	(Fairfield)	5	40	101	0.08
84	101	(Menlo Park)	17	(Fremont)	1	24	0	0.48
92	280	(Belmont)	101	(San Mateo)	2	18	24	0.27
92	101	(San Mateo)	17	(Hayward)	5	37	16	0.32
101		Oregon Border	1	(Leggett)	1	4	0	0.74
101	1	(Leggett)	129	(Cloverdale)	1	3	0	0.83
101	129	(Cloverdale)	37	(Novato)	12	26	62	0.15
101	37	(Novato)	17	(San Rafael)	7	258	58	0
101	17	(San Rafael)	1	(Mill Valley)	7	57	38	0.02
101	1	(Mill Valley)	80	(San Francisco)	1	8	0	0.55
101	80	(San Francisco)	92	(San Mateo)	13	86	42	0
101	92	(San Mateo)	84	(Menlo Park)	4	2	12	0.67
101	84	(Menlo Park)	237	(Mt. View)	10	10	70	0.24
101	237	(Mt. View)	680	(San Jose)	11	8	53	0.39
101	680	(San Jose)	152	(Gilroy)	8	8	27	0.32
101	152	(Gilroy)	156	(Prunedale)	5	12	61	0.29
101	156	(Prunedale)	183	(Salinas)	2	2	14	0.75
128	1	(Albion)	101	(Cloverdale)	3	9	0	0.38
156	1	(Castroville)	101	(Prunedale)	2	16	0	0.26
237	101	(Mt. View)	17	(Milpitas)	12	53	28	0.04
238	17	(San Lorenzo	580	(Castro Valley)	3	13	6	0.32
280	101	(San Francisco)	1	(Daly City)	8	132	42	0
280	1	(Daly City)	92	(Belmont)	4	4	22	0.52
280	92	(Belmont)	17	(San Jose)	4	18	8	0.33
280	17	(San Jose)	101	(San Jose)	10	174	68	0
580	80	(Oakland)	238	(Castro Valley)	14	177	78	0
580	238	(Castro Valley)	680	(Pleasanton)	3	12	4	0.72
680	580	(Pleasanton)	24	(Walnut Creek)	12	16	47	0.52
680	580	(Pleasanton)	17	(San Jose)	1	15	0	0.73

Source: U.S.G.S., K. V. Steinbrugge, SYSTAN

assumed to be subjected to the same earthquake intensity. The treatment of the bridge depended on its characteristics. Bridges with continuous girders were treated as a single entity. These included both continuous girder and arch bridges. Culverts were treated as single structures even though there are sometimes two or more side by side. Simple spans were treated as though each span is acted on independently, because one span can fall without having a serious impact on the balance of the bridge. Using the data in Exhibit 18, a probability of failure was estimated for each bridge of each route segment depending on whether the bridge is part of the route segment or crosses it. Using the above equation, the failure probabilities were combined to estimate the probability that all bridges on the route segment would survive. These probabilities are listed in the last column of Exhibit 19.

The route segments listed in Exhibit 19 are variable in terms of length, number of bridges and number of spans. The longest segment, Route 1 along the north coast, is more than 200 km long; most route segments in the Bay Area are 20 km or less. The number of bridges per route segment vary from one to 18. Four is the most frequent number and 6.3 is the mean. The number of main and approach spans varies from a single span to the 477 spans in the Richmond-San Rafael Bridge. Elevated freeways through San Francisco, Oakland and San Rafael also have large numbers of spans as do the elevated structures crossing marshy river bottoms, like the bridge on Route 37 across the mouth of the Petaluma River. Using Caltrans structure data, the spans were divided between those on the route segment and those over it. Some spot checks were made to assure that the records were being interpreted correctly.

The calculations of survival probabilities for the 46 route segments yield varied results. Route segments with only a few independent spans have a reasonable chance of survival even if subjected to Rossi-Forel IX intensity. In contrast, long bridges and elevated structures have so great an exposure to earthquake damage that the likelihood of their escaping unscathed is virtually nil.

When viewed as a group, the 46 route segments exhibit the following distribution of survival probabilities:

Probability of Survival	No. of Route Segments
0 to 9%	17
10 to 19	1
20 to 29	4
30 to 39	8
40 to 49	4
50 to 59	4
60 to 69	1
70 to 79	6
80 to 89	1

The data form three clusters: between 0 and 9 percent; between 20 and 59 percent and between 70 and 79 percent. Segments whose probability of survival is less than ten percent should clearly be ruled out of any contingency plan. Those whose probability of survival is greater than 70 percent are good candidates for post-earthquake use. The central group poses something of a problem. One could arbitrarily assert that segments should be considered available if the probability of bridge survival is 50 percent or greater. Such an approach is not satisfying because the analytical method does not reflect the unique environment of individual bridges. It would be more satisfying to inspect the bridges on these route segments and to make a more thorough investigation into their chances for survival. Unfortunately, this step was beyond the scope of the present research.

Ground Failure

Use of highways can be denied by ground failure that allows roadbeds to slump or slide or by embankment failures that produce slides that block highways. Both types of failures can be quickly repaired if not extensive; however, extensive failures can require many months to repair. Ground failure is most likely to occur where there are strata of clay-free granular deposits beneath a roadway. Under intense shaking, these strata will liquify and

flow like a fluid, removing support from the strata above. Unconsolidated material is also likely to fail due to lateral movement and slumping.

Potential highway failures were estimated from geological maps that identify areas of most likely ground failure. In the San Francisco Bay area, these include the Bay front property on both sides of the Bay and the river estuaries on the north and south ends of the Bay. Highway route segments that may be susceptable to ground failure include:

Highway	Between Highway	and Highway	Bridge survival probability >50%
1	280	92	Yes
17	80	238	No
17	238	84	No
17	84	237	Yes
17	237	101	Yes
37	101	12	No
80	101	17	No
80	17	17	No
84	101	17	Yes
92	101	17	No
101	37	17	No
101	80	92	No
101	92	84	Yes
101	84	237	No
101	237	680	No
237	101	17	No

Of these 16 route segments, the failure of all but five has already been predicted on the basis of bridge damage. Bridges on and over the five segments would be expected to survive, but these route segments are judged unavailable due to ground failure.

Highways could be blocked by slides in many areas where they are adjacent to unconsolidated embankments. The most likely of these instances are:

Highway	Between Highway	and Highway	Survival Probability >50%
1	280	92	No
1	101	101	No
80	17	4	Yes
80	4	505	No
92	1	280	Yes
101	1	80	No
280	92	17	Yes

Slides would block the three route segments that otherwise would have been expected to remain open. Slides on the other segments would compound other problems that would already have forced closure. In addition some displacement of Routes 1, 17, 92, and 129 should be expected where they cross the fault. Displacements as great as six meters were observed in the 1906 earthquake. In addition, pavement would be likely to buckle at the fault line; fissures may be opened and other disturbance could occur that would prevent the highway's use.

The Surviving Highway Network

A north San Andreas Fault earthquake would cause severe disruption to highway transportation along the northern California coast, and as far south as Monterey County. Exhibit 20, which illustrates the highway network, shows that state Route 1 would be unavailable north of San Francisco. Many bridges across rivers and inlets would be destroyed or severely damaged. Soil failures and slides would cause further damage. Some coastal cities would be accessible via state highways 20 and 128. Others would be totally isolated or accessible only by sea.

Highway 101 would be usable to the outskirts of Santa Rosa. Detours on city streets may keep a route open as far south as state Route 116 at Petaluma. Highway 116 would provide access to Napa, Vallejo and the east. Even so, Marin County would be completely isolated, having no access roads. Traffic around Vallejo would be impaired by damage to Interstate 80, but Solano county communities would still have highway access.

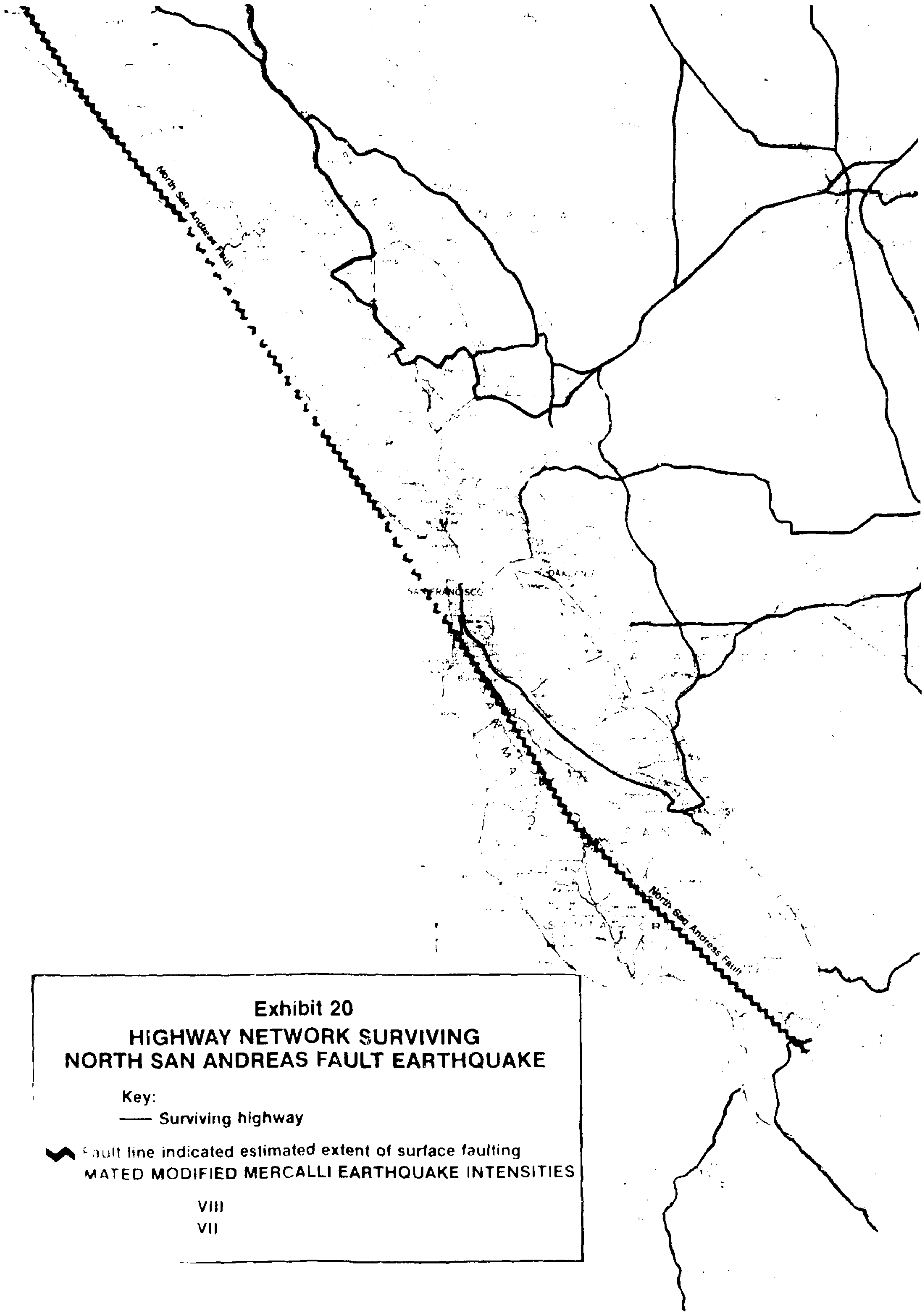
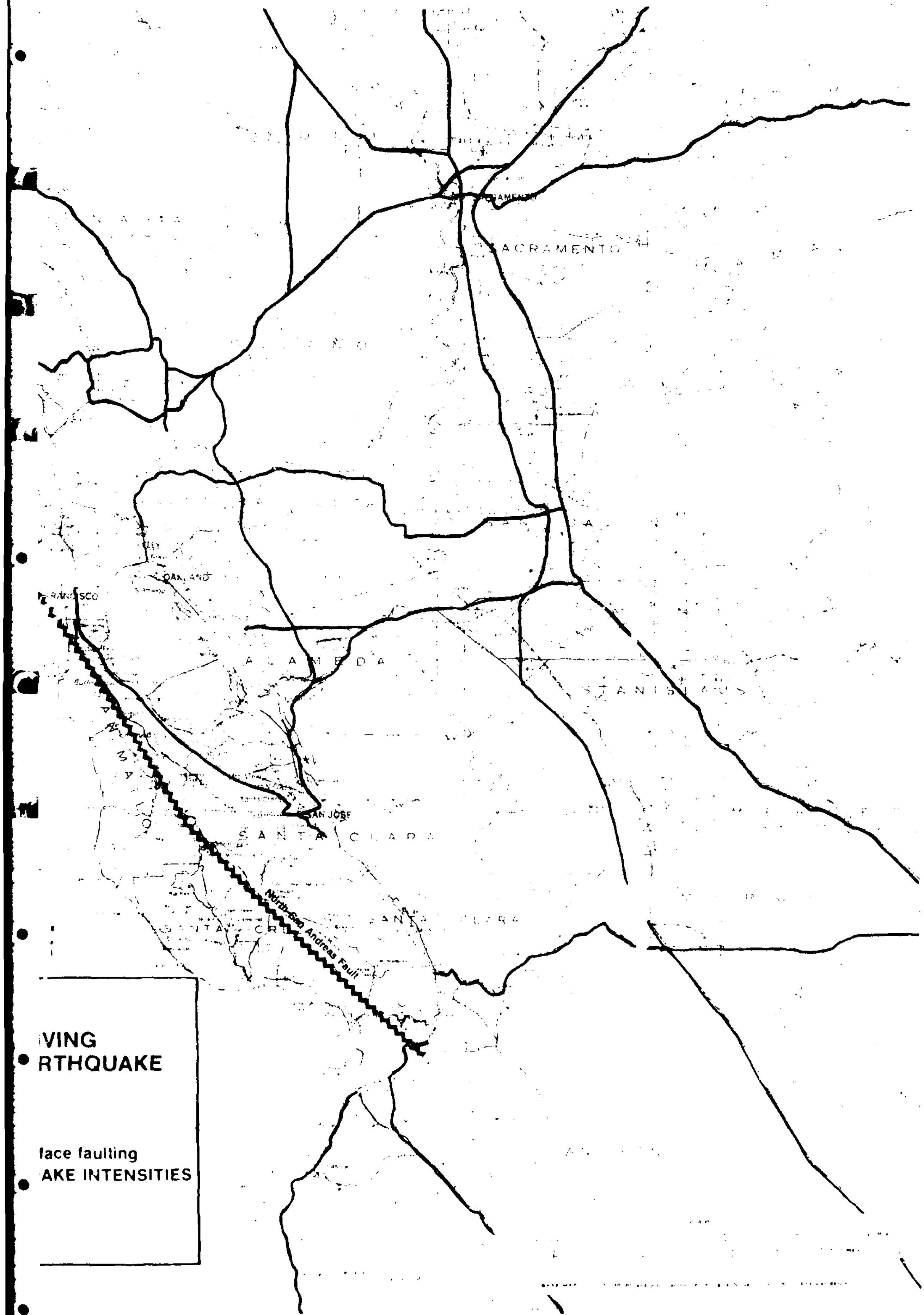


Exhibit 20
HIGHWAY NETWORK SURVIVING
NORTH SAN ANDREAS FAULT EARTHQUAKE

Key:
—— Surviving highway

Fault line indicated estimated extent of surface faulting
MATED MODIFIED MERCALLI EARTHQUAKE INTENSITIES

VIII
VII



ACRAMENTO
OAKLAND
SAN JOSE
A L A M E D A
S T A N I S L A U S
S A N T A C L A R
North San Andreas Fault
VING
RTHQUAKE
face faulting
AKE INTENSITIES

San Francisco would not be accessible via any of the highway route segments. It seems likely that an emergency route could be based on State Route 82 (El Camino Real), using detours around fallen overpasses at Routes 92, 84 and elsewhere in the San Jose area. Although the Golden Gate Bridge is likely to survive the earthquake, the southern approaches are not. The San Francisco-Oakland Bay Bridge is likely to suffer ground failures on the eastern approaches as are the other trans-bay bridges. As a result, San Francisco would be accessible only from the south and then only on an emergency basis.

State Highway 17 and Interstate 80 are likely to be closed along the East Bay by both bridge and ground failures. Interstate 580 is also likely to suffer bridge failures, especially in its elevated portions. Limited access to the East Bay may be available via State Route 4 and Interstate 580 which could discharge to surface streets near Castro Valley. Surface streets would need to be widely used, and many of these would be at least partly blocked by debris. There would be no surviving north-south route in the East Bay, unless an emergency route could be structured around San Pablo Avenue. Richmond and El Cerrito might be reached via surface streets from State Route 4. Emergency routes from Interstate 580 would be needed to reach Oakland and Berkeley. South Bay communities could be reached from Interstate 680.

There would also be serious disruption south of the Bay Area. State Routes 17 and 1 to Santa Cruz would be broken or blocked by fallen bridges. Santa Cruz would not be accessible from the south or east because of damage to State Routes 1 and 129. Perhaps a temporary route could be established over State Route 152. This would require some repair work because Route 152 crosses the fault. San Juan Bautista and Hollister are also likely to be isolated.

Post Earthquake Highway Capabilities

Outside of the Bay Area, the north coast and the Monterey Bay, post-earthquake highway capability would not be impaired.

The major intercity corridors would remain open to the outskirts of the Bay Area. Emergency supplies and food could be brought to staging areas in Vallejo, Concord, Petaluma, Livermore and Gilroy. Distribution from these points would be difficult and would depend on the speed with which emergency routes could be cleared. North south traffic could easily bypass the Bay Area using Interstate 5 and State Route 99. There would adequate highway capacity to provide normal service to communities outside of the damaged area.

It is not feasible to formulate an exact expression for highway capability within the damaged area. A creative and perhaps desperate surviving population is likely to establish emergency routes using city streets, portions of state and county roads and a combination of temporary detours. Nonetheless, some notion of the plight of the damaged area can be gained by examining the post-earthquake capability of the different route segments. The following tabulation lists approximate lanes of highway access that are available to counties in the earthquake damage zone and the lanes of highway access most likely to be available after the example earthquake:

County	Pre-earthquake one-way access lanes	Post-earthquake one-way access lanes
Sonoma	3	2
Marin	8	0
Solano	7	5
Contra Costa	7	1
Alameda	15	2
San Francisco	15	1
San Mateo	18	1
Santa Clara	15	2
Santa Cruz	5	1
San Bonito	3	0

Of the eleven counties listed, two would be completely isolated and four would be limited to a single access lane. Even these lanes would have greatly reduced capacity due to debris, lack of

power for traffic control and detours. Thus, in much of the Bay Area, post-earthquake highway capacity would be reduced by 90 percent or more.

The capacities of the surviving highway lanes will depend on the quality of the surviving traffic control and on the the speeds that can be made good around detours and other bottle necks. As speed decreases, capacity declines. The following tabulation gives approximate freeway and surface street capacities for different speeds.

Speed kph	Capacity, Automobile Equivalents/hour	
	Freeway/Interstate	Surface Street
60	1,600 - 2,000	800 - 1,000
40	1,200 - 1,600	600 - 800
25	800 - 1,200	400 - 600
15	600 - 800	300 - 400
8	400 - 600	200 - 300

Thus a detour that requires speed to be reduced to 8 kph would reduce highway capacity by about 75 percent. For planning purposes, it is probably prudent to expect highways to support no more than half of their free flow capacities. This is equivalent to an average speed of about 25 kph.

Priorities for Repairs

The time required to return damaged route segments to service will depend on the extent of damage to each segment and on the availability of maintenance crews and equipment to perform the work. An earthquake contingency plan should identify vital route segments and direct efforts toward restoring them. In the absence of such a plan, one can suggest that the greatest returns might be realized by focusing attention on the least damaged segments. These include:

Highway	Between Highway	and Highway
1	92	17
1	129	156
17	237	101

If all three route segments were opened, they would provide access to coastal portions of the San Francisco Peninsula, some access to Santa Cruz and an additional route in the south bay. If work on the two segments of Route 1 was augmented by additional work to clear a path to and through Santa Cruz and work on Route 1 north of Route 92, this route segment could be part of essential service to Santa Cruz, Pacifica and Half Moon Bay. Work on Highway 17 could be supplemented by additional work to clear a route to Oakland and Berkeley from the south. Using access to Highway 101 via Pacheco Pass (Route 152) this would help to open an emergency supply line. Before selecting specific emergency routes, other alternatives should be explored so that the limited repair resources could be used to best advantage.

RAILROAD TRANSPORTATION

Damage to the railroad track network would resemble highway damage. Both bridge damage and ground failure are likely to be widespread. The surviving network would have only limited access to the San Francisco Bay Area.

Structural Damage

Considerable information is available on the effects of earthquakes on railroad bridges in the San Francisco Bay Area. With the exception of the Western Pacific, most of the principal rail lines were in place in 1906. Damage to rail structures was recorded in the Carnegie report in considerable detail. Although damaged bridges were rebuilt to more modern standards the post 1906 designs did not reflect seismic standards that are generally accepted today. Records on railroad damage caused by the 1952 Tehachapi earthquake and the 1933 Long Beach earthquake were also useful. Railroad bridges tend to be both older and simpler than highway bridges. Most bridges across streams or narrow drainage passages have simple spans of deck plate girders or beams. Longer spans use simple trusses supported on piers. Only a few of the more recent bridges have continuous structural members.

Historical damage to railroad bridges is consistent with the estimates presented in Exhibit 18. These same probabilities were therefore used to estimate each railroad route segment's probability of survival. Sixteen route segments have bridges that would be subject to R-F VIII intensities or greater. These include some substantial bridges, such as are listed in Exhibit 21.

One can immediately dismiss the six movable element bridges from post earthquake consideration. A shock intensity R-F VII or greater is almost certain to displace a pier or movable element sufficiently to prevent post earthquake operations until substantial repairs have been completed. The SP's Pajaro River Bridge is particulary vulnerable because it lies very near to the fault, if not on it. Although one span of this bridge collapsed in the 1906 earthquake, the bridge was rebuilt with four simple deck plate girder spans. Another major earthquake would likely bring the bridge down again. The impact of the earthquake on the other bridges and smaller bridges on the route segments will depend on shock intensity, geologic underpinnings and bridge characteristics.

Exhibit 22 lists the 16 route segments most likely to be damaged together with the number of bridges and spans in each segment. Survival probabilities, calculated with the highway equation, are listed in the last column. Of the 16 route segments, only two--SP: Oakland to Martinez and WP: Oakland to Fremont--have higher than a 50 percent probability of survival. Neither of these segments contains a movable element bridge. The twelve route segments with survival probabilities of 30 percent or less should not be included in any contingency plans.

Tunnels

The sixteen route segments of Exhibit 22 contain 14 tunnels that range in length from 80 to 1706 meters. These are located on the following six route segments:

EXHIBIT 21

KEY NORTHERN CALIFORNIA RAILROAD BRIDGES

RR	Route Segment	Bridge Length (meters)	Type	Crossing
SP	San Jose to Watsonville	151	Simple spans deck plate girder	Pajaro River
SP	Hayward to Pleasanton	147	Through plate girder	Sunol Creek
SP	Hayward to Pleasanton	140	Girder and pin truss	Alameda Creek
SP	Newark to Santa Clara	254	Through plate girder	Warm Springs Creek
SP	Newark to Santa Clara	195	Through girder	Coyote Creek
SP	Newark to Santa Clara	151	Concrete girder	Marsh
SP	Fremont to San Jose	91	Deck plate girder	Coyote Creek
SP	Redwood City to Fremont	2304	Through riveted span draw bridge	San Francisco Bay
SP	Redwood City to Fremont	128	Deck plate girder	Newark Slough
NWP	Novato to San Rafael	337	Roll lift	Corte Madera Creek
NWP	Schellville to Novato	86	Through girder lift draw bridge	Sonoma Creek
NWP	Schellville to Novato	440	Through rivited swing span	Petaluma Creek
NWP	Novato to Healdsburg	83	Through riveted swing span	Petaluma Creek
ATSF	Richmond to Port Chicago	512	Steel girder	Alhambra Valley
SP	Martinez to Fairfield	1708	Through truss lift span	Sacramento River

EXHIBIT 22

PROBABILITY THAT RAILROAD ROUTE SEGMENTS WOULD SURVIVE NORTH SAN ANDREAS FAULT EARTHQUAKE

Route Segment			Bridges Subjected to Damaging Shocks			Probability None Damaged
RR	From	To	Bridges	Spans RR Over	Spans RR Under	
SP	San Francisco	Redwood City	2	2	10	0.48
SP	Redwood City	San Jose	5	5	14	0.29
SP	San Jose	Watsonville	11	22	8	0.07
SP	Redwood City	Fremont	7	109	3	0
SP	Oakland	Newark	9	12	11	0.16
SP	Newark	Santa Clara	7	20	6	0.09
SP	Fremont	San Jose	7	10	6	0.26
SP	Hayward	Pleasanton	8	15	8	0.14
SP	Oakland	Martinez	3	3	2	0.66
NWP	Schellville	Novato	2	15	2	0.19
NWP	Novato	San Rafael	5	27	12	0.03
NWP	Novato	Healdsburg	7	11	2	0.28
ATSF	Richmond	Pt. Chicago	15	15	6	0.15
WP	Pleasanton	Fremont	5	8	2	0.39
WP	Oakland	Fremont	3	3	5	0.56
SP	Oakland	Hayward	9	9	7	0.27

RR	Route Segment	No. of Tunnels	Lengths, meters
SP	San Francisco to Redwood City	4	1,081, 721, 554, 331
SP	Oakland to Martinez	1	184
NWP	Novato to San Rafael	2	414, 307
NWP	Novato to Healdsburg	3	537, 106, 80
ATSF	Richmond to Port Chicago	2	1,706, 375
WP	Pleasanton to Fremont	2	1,317, 124

Some tunnels are unlined, others contain concrete, gunite or timber linings. The four tunnels in San Francisco are brick and concrete lined.

Past experience suggests that tunnels are unlikely to fail unless they lie on the fault break (as was the case in the 1952 Tehachapi earthquake). However, there is danger of earth slides at tunnel portals. Of the six route segments, five are likely to be out of service because of bridge damage. The remaining one--SP: Oakland to Martinez--should be checked for slide potential. The tunnel on this route segment is unlikely to be damaged.

Ground Failure

Railroad lines are subject to both ground failure and slides. Ground failure under rail lines is particularly likely in the East Bay, the South Bay, the Suisun Marsh along the Sacramento River, and along the Petaluma River. The 1906 earthquake caused liquifaction ir the Suisun Marsh. The ground settled as much as three meters, causing considerable damage to rail lines. Ten rail route segments are susceptable to damage from ground failure:

RR	Segment
SP	Redwood City to Fremont
SP	Oakland to Newark
SP	Newark to Santa Clara
SP	Fremont to San Jose
SP	Martinez to Fairfield
SP	Napa to Schellville
NWP	Schellville to Novato
NWP	Novato to San Rafael
NWP	Novato to Healdsburg
ATSF	Richmond to Port Chicago

All but one of these route segments have already been eliminated because of potential bridge failures: eight from the analysis presented in Exhibit 22 and the Martinez to Fremont segment because of its movable element bridge across the Sacramento River. Therefore, ground failure for these segments will merely add to the problems of rehabilitating these route segments. The tenth segment--SP: Napa to Schellville (west of Napa)--is likely to be unavailable because of ground failure.

Slides are likely to block both the SP and WP lines through the Niles Canyon (Fremont to Pleasanton route segment). There may also be damaging slides near tunnel portals in San Francisco and on the SP and ATSF routes between Richmond and Martinez. Of these, the SP's Oakland to Martinez route segment is the only one likely to escape closing because of bridge failures.

The Surviving Railroad Network

The north San Andreas Fault earthquake would eliminate all railroad service west of Pleasanton-Concord and north to Watsonville. As illustrated in Exhibit 23, the Northwestern Pacific would be isolated with no connection to any other railroad. The WP would be open from Stockton as far as Pleasanton, but not beyond. The ATSF would be open as far west as Port Chicago (near Pittsburg). The SP would have the most extensive surviving network, but even that would be limited. Surviving lines would extend from Sacramento west to Napa; from Stockton northwest to Concord and west to Pleasanton and from Salinas north to Watsonville. There would also be a surviving line connecting Concord with Pleasanton. The major yards and terminals in the Bay Area would be inaccessible.

The statewide impact of the earthquake would be to isolate the Bay area, to eliminate use of the NWP and to isolate the coast route between San Francisco and Los Angeles. Other service could continue as usual. The heavy north south traffic that travels

through the Central Valley would be unaffected as would service to southern California from the north and east.

Post-earthquake railroad capability would be limited by the ability to unload and to handle freight cars. The major yards and terminals in the Bay Area could be inaccessible. The sidings, spurs and industrial tracks in the Concord-Pleasanton area would be insufficient to support more than three or four trains per day--amounting to 200 to 400 cars. Thus, car handling would reduce the railroad supply capability to the Bay Area from over 100 trains per day to four or fewer.

In considering repairs, first priority should be given to reestablishing service to the Bay Area both to support the surviving population and to reestablish access to the major railroad terminals. Slide clearing and repairs in Niles Canyon could open the SP and WP lines to Oakland. Service to San Francisco poses a serious problem because of South Bay soil failures. The best approach may be to repair the Pajaro River bridge and to reopen the coast route as far as possible. Reopening the NWP would require a herculian effort; in fact a major earthquake may be the death knell for the NWP because of its marginal profitability.

PIPELINE TRANSPORTATION

The pipeline supply networks are much simpler than either the highway or railroad networks, but damage assessments are more difficult because:

- The impacts of earthquake intensities on pipelines are not well known, and
- Pipeline damage is heavily dependent on geologic structure and structural changes which are not well known.

Nonetheless, some reasonable statements can be made about the impact of a North San Andreas Fault earthquake on both natural gas and petroleum supply pipeline networks.

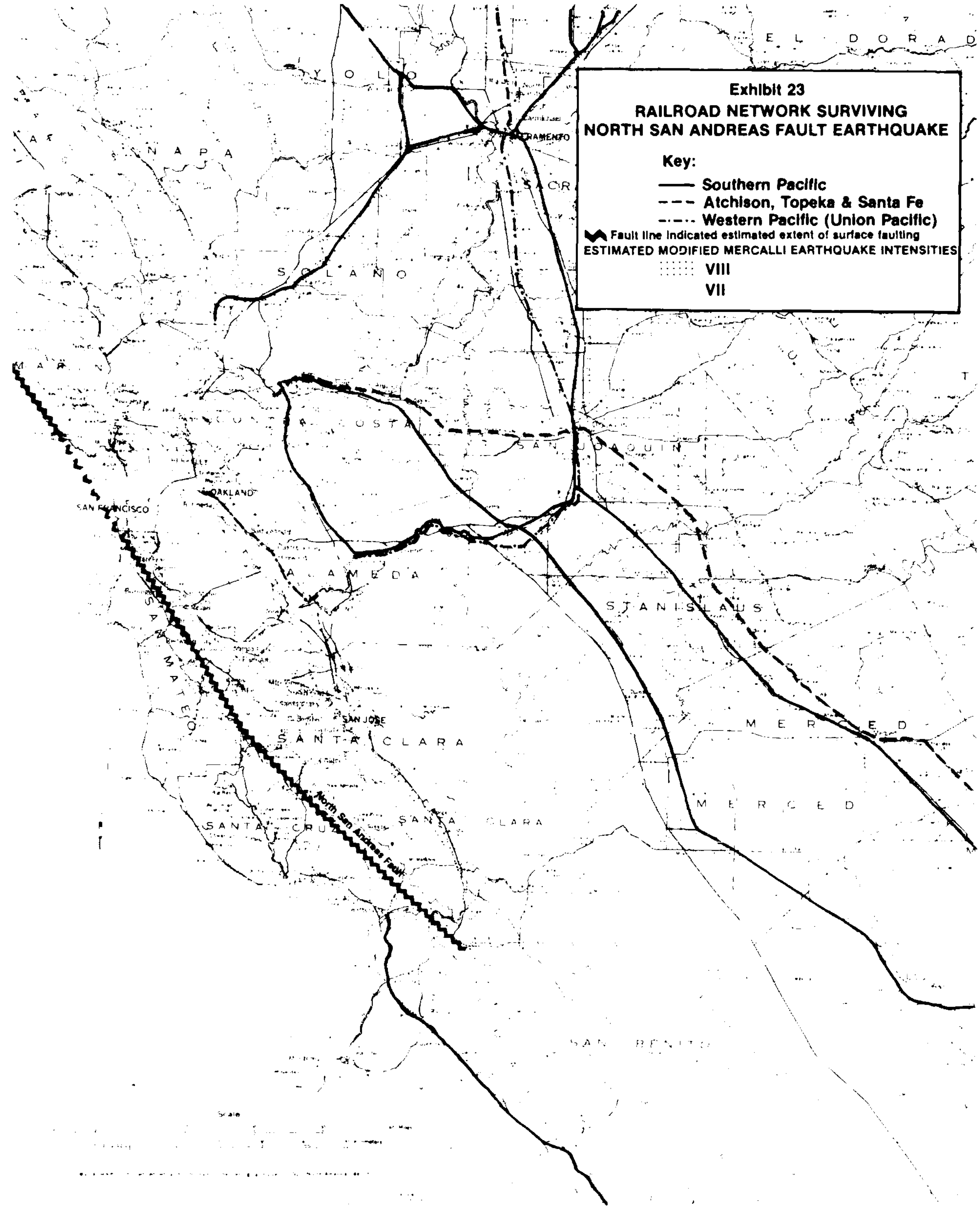


Exhibit 23
RAILROAD NETWORK SURVIVING
NORTH SAN ANDREAS FAULT EARTHQUAKE
Key:
Southern Pacific
Atchison, Topeka & Santa Fe
Western Pacific (Union Pacific)
Fault line indicated estimated extent of surface faulting
ESTIMATED MODIFIED MERCALLI EARTHQUAKE INTENSITIES
VIII
VII
YOLO
NAPA
SOLANO
EL DORADO
SAN JOAQUIN
STANISLAUS
MERCED
SAN FRANCISCO
OAKLAND
ALAMEDA
SAN MATEO
SAN JOSE
SANTA CLARA
SANTA CRUZ
SAN BENITO
North San Andreas Fault

Natural Gas Pipelines

The natural gas pipeline network serving the San Francisco Bay Area (see Exhibit 7), consists of major supply pipelines with some redundancy, gas distribution terminals, control and metering equipment, and limited storage facilities, principally above ground holders.

High pressure gas lines (55 atmospheres), with heavy walls and strong couplings, have considerable resistance to earthquake damage. The major natural gas supply lines to Northern California did not rupture in the 1952 Tehachapi earthquake despite the fact that their lines crossed the White Wolf fault at points where surface faulting occurred.

Pipelines are most susceptable to damage by ground failures, differential earth movements, and earth slides that would apply considerable stress to underground pipelines. Additional sources of potential damage occur where piplines are attached to compressors or other structures that are mounted on heavy foundations.

The three major access lines to the Bay Area are all subject to earthquake induced breaks:

- The Northern line passes through poor soil near Fairfield that has a high liquifaction potential;
- The Central line passes through poor soil near Concord that has a high liquifaction potential; and
- The Southern line is subject to damage by land slides in the Niles Canyon.

If these breaks were to occur, natural gas would be unavailable to either the Bay Area or to regions south of the Bay Area. If breaks could be isolated locally a line branching from the central supply line near Brentwood could supply the Concord, Walnut Creek, Lafayette area east of the Oakland hills.

If one or more of the major supply lines survived the earthquake without damage, natural gas would still be denied to most of

AD-A143 554 CALIFORNIA EARTHQUAKE RESIDUAL TRANSPORTATION CAPABILITY STUDY(U) SYSTAN INC LOS ALTOS CA P S JONES DEC 83 SYSTAN-D184 DOT-TSC-RSPA-83-13 2/3

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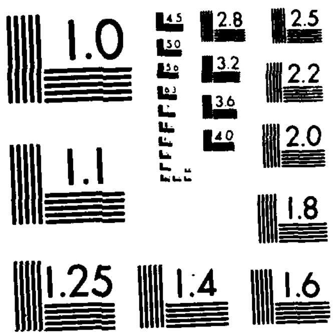


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

the Bay Area. The two supply lines to San Francisco and the San Francisco Peninsula are vulnerable. The Bayside line passes through poor soil with liquifaction potential near Redwood City, San Mateo, Milbrae and San Bruno. The inland line is on or near the San Andreas Fault a good part of the distance up the Peninsula. Both lines would be affected by damage to the Milpitas Terminal and adjacent pipelines which are on poor ground near Coyote Creek. The pipelines supplying the East Bay traverse poor soil throughout their length from Fremont to Richmond. The lines supplying Marin County and the North Coast are buried in poor soil in the Sonoma Creek bottoms near Schellville and in the Petaluma River bottoms near Petaluma. The line to southern Marin County passes through more poor soil near Novato, San Rafael, and Corte Madera.

Except for the terminal near Crockett, major terminals serving the Bay Area would be susceptible to damage. Storage facilities are also subject to damage. In past earthquakes, gas holders have fared well because of their light, flexible structures. Even so, seal distortions may render them unusable until repaired. The underground storage near San Rafael may survive.

Petroleum and Petroleum Product Pipelines

Petroleum and petroleum product pipelines are subject to damage by ground failure or differential movement or by surface failures adjacent to refineries or terminals. Storage tanks and refineries and terminals are also subject to considerable damage. The three petroleum supply lines are relatively clear of poor soil until the line to Richmond reaches unstable soil just west of Crockett. Pipelines supplying the Shell and Tosco refineries appear to have a good chance of survival. The line to Richmond may also survive. Product pipelines are not likely to fare nearly so well. The product lines extending along the East Bay pass through soil that is subject to liquifaction at many points. The transbay lines between the San Francisco and Oakand airports may fail at terminal junctions if not elsewhere. The San Jose terminals

are all near Coyote Creek where extensive ground failure can be expected. The lines cross the Oakland Hills near Piedmont and Sunol may be subject to slides and other ground failure.

Four of the six Bay Area refineries may survive the earthquake. The other two, Chevron and Exxon, are likely to suffer some damage due to ground failure even though most large structures are supported on piles. Ground failure can affect pumps, compressors, heat exchangers and pipe supports not considered large or heavy enough to require pile support. At best all six refineries will require careful checks for leaks and internal damage to fractionating columns, reactors, fired heaters and other complex components. It is likely that some shutdown of most units will be needed. Even so, sufficient capacity is likely to survive to support the Bay Area's emergency petroleum needs. Terminals will not fare well. All major terminals are located on poor soil that is subject to liquifaction.

AIRPORTS

The greatest earthquake danger to the emergency use of airports is failure of the ground under major runways so that the runways cannot support the weight of landing aircraft. Of lesser importance is the collapse of a control tower or the failure of one or more aircraft control systems. The latter damage will restrict the capacity of an airport, because aircraft will need to take off and land under visual control, and will not be able to operate during periods of low visibility. If control systems survive, most airports have adequate emergency power generation to support these vital systems.

If runway capacity were limited, the most efficient emergency supply and evacuation aircraft would be wide body commercial jets and large C-141 and C5A military transports. These aircraft require runways that are eight to ten thousand feet long and capable

of supporting heavy loads up to 350,000 kg. Smaller military aircraft like the C-130 and short take off aircraft can operate in and out of small airports and temporary air strips.

Regrettably, most of the major airports in the San Francisco Bay Area are located on filled or alluvial soil next to the Bay. Water tables are typically high--within five feet of the surface. Thus earthquake intensities would be high and ground failure would be likely. With the exception of Travis Air Force Base in Solano County, all major airports in the Bay Area would be subjected to earthquake intensitites of R-F IX or greater. Serious runway damage could be expected at the following airports:

San Francisco International
Oakland International
Alameda Naval Air Station and
Hamilton Field.

These airports should not be expected to support any aircraft operations until major repairs have been completed. Even if these airports were to survive, ground access for freight and passengers would be difficult. U.S. 101, the major access route for the San Francisco Airport and Hamilton field, would not be available to support highway traffic. Emergency routes could be constructed from nearby surface streets, but these would require some filling in areas of ground failure. Oakland airport is accessible from Route 17 which would also be blocked, buckled or settled. Emergency routes could also be constructed there. The Alameda Naval Air Station poses even greater access problems. The two tunnels under the Oakland Estuary are likely to be blocked by debris or differential settlement. Most if not all of the four bridges may be structurally damaged.

San Jose Municipal Airport and Moffett Field may be able to support limited aircraft operations. Both are located on alluvial soil with high water table, but limited investigations have not identified granular soil that is subject to liquifaction. Because

of earthquake intensities at these sites, control towers and support buildings are not expected to survive.

Travis Air Base is located on relatively solid material containing no Bay mud. It is likely to be subjected to an earthquake intensity no greater than R-F VII. As a result, both runways and control systems are likely to survive. In addition, access routes to Travis are likely to be open. With its long runways, Travis Air Base is a logical candidate for a major airport to receive and dispatch high volumes of freight and passengers.

In addition to the major airports, there are a number of small general aviation airports in the Bay Area that are capable of supporting C-130 aircraft. Unfortunately, most of these are also located near water and on land subject to liquifaction. Hayward airport is the most likely candidate for post earthquake service. It has a runway more than 5,000 ft long and is not built on Bay mud. Buchanan field in Concord is another candidate, but it is not very close to the potentially damaged area. The situation in the West Bay is not good. The smaller airports are all on land that is subject to failure. In the north Bay, there are no airfields with survival potential closer than Travis Air Base.

If sufficient helicopters and short take off aircraft were available to mount a substantial air lift, there would be 35 small heliports and short landing strips that could be placed in emergency service. Most of these are also on poor soil but as many as 15 are likely to survive the earthquake. These could support air lift to the north and west Bay areas.

WATERWAYS AND PORT FACILITIES

Port facilities are subject to several different kinds of earthquake damage:

- Pier, quay and bulkhead failure;
- Collapse of cranes, wharfs, and loading structures;
- Sliding or shifting of dredged channels; and
- Failure of access roads and railroads at or adjacent to the port.

All types of failures can be expected in San Francisco Bay as a result of a major earthquake on the San Andreas Fault.

The Port of Oakland, which operates major container terminals at its inner and outer harbors, would likely suffer extensive damage as a result of ground failures and R-F IX earthquake intensities. A combination of ground failure and shaking is likely to topple many of the container cranes. Track distortion can be expected to incapacitate the balance. Ground failure in container yards is likely to make container handling difficult if not impossible. Channel walls may also slump, preventing ships from coming alongside piers.

Across the Bay in San Francisco, damage is likely to be as intense, but it will be manifested differently. Damage to San Francisco's container terminal will be similar to Oakland's. The piers along the Embarcadero are all resting on piles and could be expected to survive; however, access would be difficult because of ground failure behind the bulkhead wall. The San Francisco Belt Railway would likely suffer extensive damage along the water front. Twisted, broken and compressed track and structures could be impediments to temporary access roads. Damage in Richmond and San Leandro would resemble that in Oakland and San Francisco. Water access to the Port of Redwood City is likely to be cut off by slumping of the walls of the narrow channel opposite San Bruno.

Port facilities at Crockett/Martinez, Vallejo and Port Chicago have a good chance of survival. Earthquake intensities on non-granular soil in these areas would not exceed R-F VII, insufficient to cause widespread damage. Even if channel walls slide, provisions can be made to use port facilities in these areas.

Although no structural investigations have been made of the major Bay crossings, there is reasonable expert consensus that the major structures of the Golden Gate, San Francisco/Oakland Bay, Richmond/San Rafael and Carquinez Bridges would remain standing. As a result, there would be water access to Crockett/Martinez and

Vallejo. However, failure of the Southern Pacific's movable element bridge at Benecia is likely to block access to Port Chicago and to the inland ports of Sacramento and Stockton.

DAMAGE OVERVIEW

When damage to all transportation modes that might survive a major San Andreas Fault earthquake is combined, the picture is not a pretty one. Highway access would be limited to a few routes with parts of Marin County and the coast north and south of San Francisco likely to be isolated. Even so, the surviving highways offer the best focus for emergency repairs. Rail service would be stopped at Fairfax, Concord, Niles Canyon and the Pajaro River effectively isolating the Bay Area. Airports and sea ports would fare little better with surviving facilities located at Fairfax the Carquinez Strait and Suisun Bay.

With only very limited transportation facilities available after an earthquake, the problems of supply and evacuation would be large. Cargoes could be brought to Fairfax by air; Crockett/ Martinez by water; Livermore and Pittsburgh by rail. From these points all distribution would have to be by highway, using surviving arteries where they exist, but depending heavily on emergency routes over surface streets. Because of the limited capacity of surviving streets and highways, emergency transportation would need to be limited to supplies essential to survival and those needed for critical emergency repairs.

Transportation repairs should focus on establishing transportation routes to the Bay Area. Highway repairs should focus on opening north south routes to Marin County, the San Francisco Peninsula and the East Bay. Rail repairs should focus on opening Niles Canyon and a route from Martinez to Richmond. Marine terminal repairs should focus on building temporary facilities with ground access in San Francisco and the East Bay.

No attempt has been made to estimate the time necessary to complete temporary repairs to transportation facilities. This will depend on the crews and equipment that survive, the mobility

of these crews within damaged areas and the priorities that are established. The essential services that command highest priority are likely to be:

Water supply;
Sewage;
Electric power; and
Transportation,

in that order. As a result, transportation repairs may be delayed a few days or a week before work begins. Once started, it would likely take two to three weeks to establish enough emergency services to provide adequate transportation to support survivors.

V. 7.5 MAGNITUDE EARTHQUAKE ON THE HAYWARD FAULT

Damage to transportation systems from a 7.5 magnitude earthquake on the Hayward Fault is likely to be similar to that already described for a North San Andreas Fault earthquake. Major differences would result from the smaller area impacted by the Hayward earthquake and from its greater intensity in the East Bay. A Hayward fault earthquake would have little impact on transportation facilities on the north coast or south of San Jose. However, major transportation routes cross the Hayward fault and may be subjected to intense damage at these points.

This chapter presents the results of the analysis of a potential earthquake on the Hayward fault. The method of analysis, which is very similar to that described in Chapter IV, is not repeated.

HIGHWAY TRANSPORTATION

An earthquake on the Hayward fault is likely to damage the highway network through (1) structural damage to bridges, (2) soil slumping or liquifaction under roadbeds, and (3) earth slides onto highways. This damage will prevent the use of many route segments until substantial repairs have been completed.

Structural Damage to Bridges

Using the U.S.G.S. computer program, earthquake intensities were estimated for each of the 1239 highway structures in the bridge inventory. Mr. K. V. Steinbrugge's damage estimates by bridge type (Exhibit 18) were applied to these structures to

calculate a probability for each. These probabilities were combined for all structures on each highway route segment to produce a probability that the route segment as a whole would be usable after the earthquake. The results of these calculations are listed in Exhibit 24.

All of the route segments around the bay would be severely impacted. Bridges on State Route 37 that cross the Petaluma River and adjacent sloughs north of San Pablo Bay are likely to be damaged; however, there would be little damage north of this route. Major north-south and east-west routes in the East Bay--I80, SR17, I580, SR238, SR24 and SR84--are likely to suffer severe structural damage. East of the Oakland Hills, structures on Interstate 680 are also likely to be damaged. In the West Bay, damage is not likely to be as severe as that expected from an earthquake on the San Andreas fault. Structures on U.S. 101 between San Rafael and San Jose are likely to be severely damaged; but little damage is expected elsewhere. Bridges on I280 south of San Francisco are likely to survive, except for the route segment in San Jose between SR 17 and U.S. 101.

Use of all five trans-Bay bridges is likely to be denied because of failures at approaches. The bridges themselves are likely to survive, though several might be structurally weakened.

Ground Failure

Ground failure in the form of roadbed or pavement damage or blocking slides is a threat on the following 19 highway route segments:

Highway	Between Highway	and Highway	Bridge survival probability >50%
1	280	92	Yes
17	80	238	No
17	238	84	No
17	84	237	No
17	237	101	No
37	101	12	No
80	101	17	No
80	505	4	Yes

EXHIBIT 24

PROBABILITY THAT HIGHWAY ROUTE SEGMENTS WOULD SURVIVE HAYWARD FAULT EARTHQUAKE

Route Segment					Bridges Subjected to Damaging Shock			
						Spans		Prob.
Hwy No.	From Highway		To Highway		Bridges	Under Hwy	Over Hwy	None Damaged
17	101	(San Rafael)	80	(Richmond)	5	458	60	0
17	80	(Oakland)	238	(San Lorenzo)	18	362	46	0
17	238	(San Lorenzo)	84	(Fremont)	8	14	36	0.15
17	84	(Fremont)	237	(Milpitas)	4	5	12	0.24
17	237	(Milpitas)	101	(San Jose)	5	12	18	0.36
17	101	(San Jose)	1	(Santa Cruz)	7	40	34	0.15
24	580	(Oakland)	680	(Walnut Creek)	18	214	28	0.01
37	101	(Novato)	12	(Vallejo)	1	57	0	0.1
80	101	(San Francisco)	17	(Oakland)	4	614	4	0
80	17	(Oakland)	17	(Richmond)	4	19	36	0.24
80	17	(Richmond)	4	(Pinole)	2	4	11	0.32
80	4	(Pinole)	680	(Fairfield)	5	40	101	0.15
84	101	(Menlo Park)	17	(Fremont)	1	24	0	0.23
92	280	(Belmont)	101	(San Mateo)	2	18	24	0.48
92	101	(San Mateo)	17	(Hayward)	5	37	16	0.21
101	17	(San Rafael)	1	(Mill Valley)	7	57	38	0.18
101	1	(Mill Valley)	80	(San Francisco)	1	8	0	0.22
101	80	(San Francisco)	92	(San Mateo)	10	82	36	0.16
101	92	(San Mateo)	84	(Menlo Park)	4	2	12	0.67
101	84	(Menlo Park)	237	(Mt. View)	10	10	70	0.24
101	237	(Mt. View)	680	(San Jose)	11	8	53	0.39
101	680	(San Jose)	82	(San Jose)	6	6	13	0.31
237	101	(Mt. View)	17	(Milpitas)	12	53	28	0.04
238	17	(San Lorenzo)	580	(Castro Valley)	3	13	6	0.14
280	101	(San Francisco)	1	(Daly City)	8	132	42	0.27
280	1	(Daly City)	92	(Belmont)	4	4	22	0.92
280	92	(Belmont)	17	(San Jose)	4	18	8	0.88
280	17	(San Jose)	101	(San Jose)	10	174	68	0.15
580	80	(Oakland)	238	(San Lorenzo)	14	177	78	0
580	238	(San Lorenzo)	680	(Pleasanton)	3	12	4	0.33
680	580	(Pleasanton)	24	(Walnut Creek)	12	16	47	0.52
680	580	(Pleasanton)	17	(San Jose)	1	15	0	0.36
680	4	(Martinez)	24	(Walnut Creek)	9	6	14	0.28

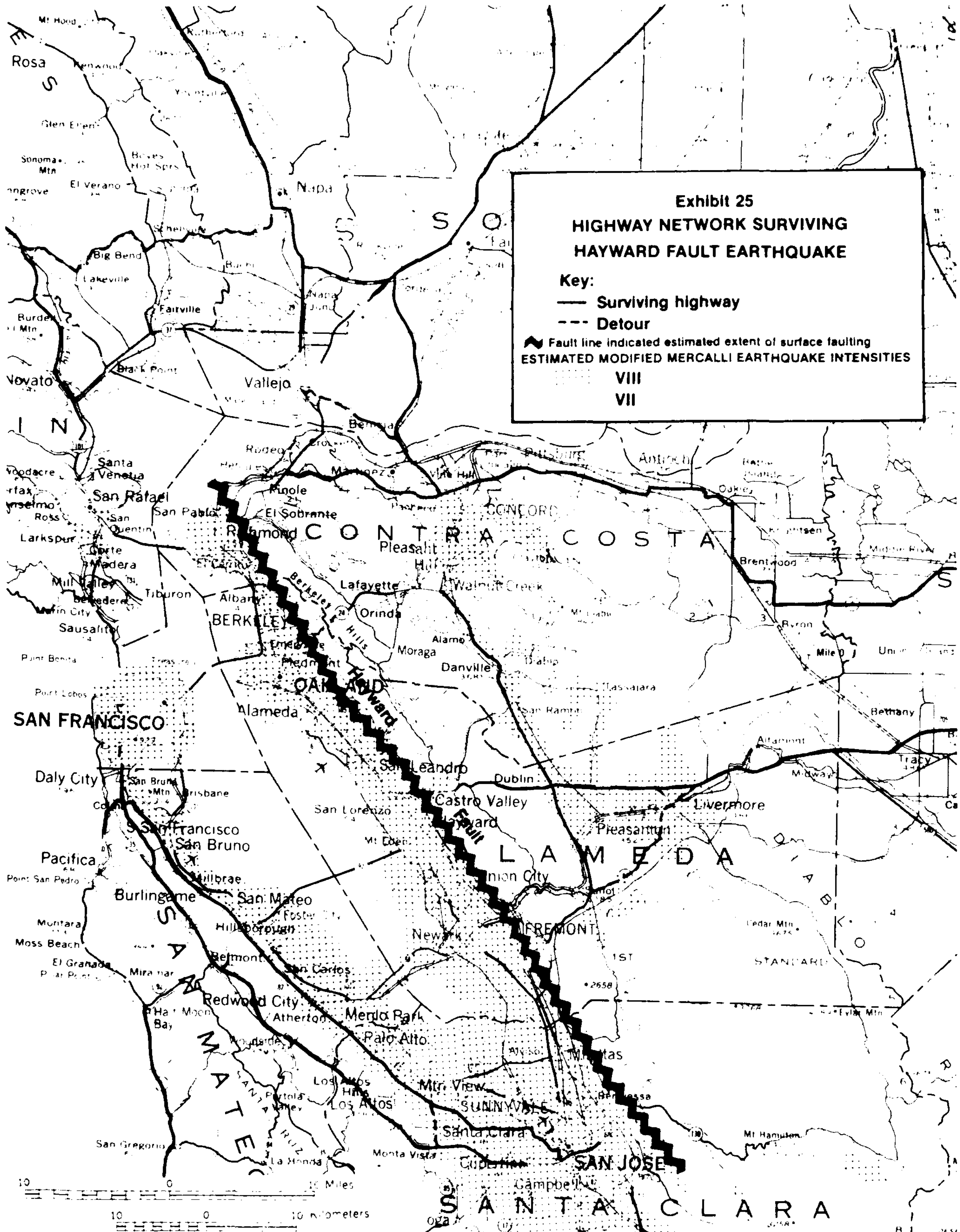
Source: U.S.G.S., K. V. Steinbrugge, SYSTAN

Highway	Between Highway	and Highway	Bridge survival probability >50%
80	4	17	Yes
80	17	17	No
84	101	17	No
92	101	17	No
92	1	280	Yes
101	37	17	Yes
101	80	92	No
101	92	84	Yes
101	84	237	No
101	237	680	No
237	101	17	No

Roadbed or pavement failure would be the predominant problem affecting 16 of the 19 highway segments. Many of these segmen are built on filled land that crosses arms of the Bay or marsh land. Slides could be a problem on U.S. 101 north of the Golden Gate Bridge, on SR1 south of San Francisco and on I80 south of the Carquinez Strait. On six of these segments, ground failure is likely to cause closure. On the other 13 segments, ground failure merely adds to the problems of rehabilitation. In some instances, ground failure can be temporarily repaired reasonably quickly if earth moving equipment is available. Because of the extent of the failure, however, only one or two segments could be restored to service in one day or less.

Surviving Highway Network

The highway network likely to survive a major earthquake on the Hayward fault could support only limited transportation to and about the San Francisco Bay Area. Exhibit 25 shows the surviving route segments. This structure is somewhat different from the highway network expected to survive a San Andreas fault earthquake. For a Hayward fault earthquake, the highway network can be expected to survive intact north of Petaluma and south of San Jose. As a result, the northern coast and the Santa Cruz-Monterey Bay area would suffer little, if any, loss of transportation. In the immediate Bay area, conditions would be comparable to or perhaps worse than those caused for a San Andreas earthquake. With the



BASE MAP Compiled, edited and published by the Geological Survey

loss of the southern portion of I680, transportation to Santa Clara County would be available only via SR152 (Pacheco Pass) and U.S. 101 from the south. Distribution around the San Jose area would be difficult, but there are an abundance of surface streets and expressways from which to fashion emergency routes. Access to Marin County would be available from the north via U.S. 101 and from the east via I80 with detours through Napa and Petaluma.

The East Bay would have serious transportation problems. There would be no access via major highways. SR4 would be open most of the way, but it would almost certainly be damaged where it crosses the fault. Access via I580 would likely terminate at the Pleasanton intersection with I680, though a detour may carry it further. Because of intense damage throughout the East Bay, it would be difficult to establish either an emergency route or local distribution routes.

San Francisco is likely to be isolated by this earthquake. Fallen bridges would likely block most potential surface routes. Debris clearance and/or detours would be needed to establish an emergency route via SR82 (El Camino Real) or I280.

The San Francisco Peninsula and coastal San Mateo County would fare better under a Hayward than a San Andreas fault earthquake. I280 would provide access through the county. Although feeder highways are awkward to this mid-peninsula freeway, access would likely be possible. With detours around key bridges, SR82 could likely be established as an emergency route.

Post-Earthquake Highway Capability

Although general expressions of post-earthquake highway capability are subject to misinterpretation, some notion of the situation can be gained by considering the number of access routes to each county that are likely to survive. The following tabulation lists numbers of lanes in each direction for pre-earthquake and post-earthquake highway capacity:

County	Capacity, Lanes in Each Direction Pre-Earthquake	Post-Earthquake
Sonoma	4	3
Marin	8	2
Contra Costa	7	1
Alameda	15	1
San Francisco	15	1
San Mateo	18	5
Santa Clara	15	3
Santa Cruz	5	3

Alameda, Contra Costa and San Francisco Counties would be hard hit, with at best a single emergency highway open. Marin, S[illegible]eo and Santa Clara Counties would have serious problems, but w[illegible]have multiple access routes, some of moderate to good quality. [illegible]though suffering relatively little earthquake damage, Sonoma and Santa Cruz Counties would lose the use of valuable access routes from the Bay Area.

RAILROAD TRANSPORTATION

Railroad lines in the Bay Area would be severely damaged by a major earthquake on the Hayward fault. Both bridge damage and ground failure would be widespread, leaving limited access to the Bay Area and limited terminal facilities at the ends of the surviving lines.

Structural Damage to Bridges

A major Hayward fault earthquake is likely to cause misalignment to the six railroad bridges listed in Exhibit 21 as having movable elements. The loss of these bridges which cross San Francisco Bay, the Sacramento River, the Petaluma River, Sonoma Creek and Corte Madero Creek would severely disrupt rail service between Sacramento and Oakland and to Marin County. The loss of these bridges would deny the use of the following route segments:

Crossing	Route Segment	Railroad
San Francisco Bay	Redwood City-Fremont	SP
Sacramento River	Martinez-Fairfield	SP
Petaluma River	Fairfield-Novato	SP/NWP
Petaluma River	Novato-Eureka	NWP
Sonoma Creek	Fairfield-Novato	NWP
Corte Madero Creek	Novato-San Rafael	NWP

These losses would isolate the Northwestern Pacific by denying its connection with the Southern Pacific. Loss of the Sacramento River bridge would deny use of the SP's main line between Fairfield and Oakland. There are detours around the Bay Crossing between Fremont and Redwood City.

Structural damage to fixed bridges will greatly increase railroad network damage. Exhibit 26 lists the probabilities that 17 route segments would survive the earthquake. Of these, five would already have been rendered unavailable by the loss of movable element bridges. Only two--Novato to Healdsburg, and Pleasanton to Martinez--have greater than 50 percent probability of survival. Although the survival probability of the San Francisco to Redwood City route segment is close to 50 percent, this segment could count on no surviving connection.

Tunnels

The 18 route segments listed in Exhibit 26 contain 14 tunnels that vary in length from 80 to 1706 meters. These are located on the following six route segments:

RR	Route Segment	No. of Tunnels	Lengths, meters
SP	San Francisco to Redwood City	4	1,081, 721, 554, 331
SP	Oakland to Martinez	1	184
NWP	Novato to San Rafael	2	414, 307
NWP	Novato to Eureka	3	537, 106, 80
ATSF	Richmond to Port Chicago	2	1,706, 375
WP	Pleasanton to Fremont	2	1,317, 124

EXHIBIT 26

PROBABILITY THAT RAILROAD ROUTE SEGMENTS WOULD SURVIVE HAYWARD FAULT EARTHQUAKE

Route Segment			Bridges Subjected to Damaging Shocks			Probability None Damaged
RR	From	To	Bridges	Spans RR Over	Spans RR Under	
SP	San Francisco	Redwood City	2	2	10	0.48
SP	Redwood City	San Jose	5	5	14	0.29
SP	San Jose	Watsonville	11	22	8	0.32
SP	Redwood City	Fremont	7	109	3	0
SP	Oakland	Newark	9	12	11	0.04
SP	Newark	Santa Clara	7	20	6	0.06
SP	Fremont	San Jose	7	10	6	0.15
SP	Hayward	Pleasanton	8	15	8	0
SP	Oakland	Martinez	3	3	2	0.23
SP	Pleasanton	Martinez	10	17	11	0.72
SP	Martinez	Fairfield	6	22	8	0.69
NWP/ SP	Fairfield	Novato	2	15	2	0.32
NWP	Novato	San Rafael	5	27	12	0.21
NWP	Novato	Healdsburg	7	11	2	0.78
ATSF	Richmond	Pt. Chicago	15	15	6	0.08
WP	Pleasanton	Fremont	5	8	2	0
WP	Oakland	Fremont	3	3	5	0.22
SP	Oakland	Hayward	9	9	7	0.18

Three of these route segments cross the Hayward fault--Oakland to Martinez, Richmond to Port Chicago and Pleasanton to Fremont. Tunnels on or near the fault are expected to suffer damage, after the fashion of the railroad tunnels damaged by the Tehachapi earthquake. Earthquake intensities on the Novato to Eureka route segment would be sufficiently low that tunnel damage is unlikely. Tunnels on the San Francisco to Redwood City and Novato to San Rafael segments are likely to survive, but there may be damage to portals and slides near entrances. The tunnel analysis does not add to the list of route segments likely to be unusable after the earthquake.

Ground Failure

Ground failure under road beds and slides that block lines are likely to affect at least ten railroad route segments:

RR	Segment
SP	Redwood City to Fremont
SP	Oakland to Newark
SP	Newark to Santa Clara
SP	Fremont to San Jose
SP	Martinez to Fairfield
SP	Hayward to Pleasanton
NWP/SP	Fairfield to Novato
NWP	Novato to San Rafael
ATSF	Richmond to Port Chicago
WP	Pleasanton to Fremont

Ground failure under roadbeds is likely to affect the eight route segments near the San Francisco Bay and across marsh land north of San Pablo and Suisun Bays. The two segments routed through Niles Canyon--Pleasanton to Fremont and Hayward to Pleasanton--are vulnerable to slides that could block right of way. Slides are also possible on the Novato to San Rafael route segment.

All ten route segments would also have problems with bridges and/or tunnels. Therefore, while ground failure would complicate repairs and emergency services, it would not add to the list of route segments that would be unavailable for post-earthquake service.

The Surviving Railroad Networks

A major earthquake on the Hayward fault would interrupt all railroad service in the San Francisco Bay area. All route segments of the extensive SP railroad network would be blocked by damaged bridges, roadbed failure or slides. SP access from the east would terminate at Fairfield and Pleasanton. Access from the south would reach only as far as Morgan Hill. The Sacramento-Oakland line is likely to be usable as far west as Fairfield, but ground failures in the Suisun swamps and damage to the Sacramento River bridge at Martinez would prevent service west of Fairfield. Service to Marin County and the NWP would be disrupted by either damage to one or both of the movable element bridges across Petaluma River and Sonoma Creek, or ground failure north of San Pablo Bay or both. Damage along this route segment would isolate the NWP which would likely remain intact north of Novato. The line from Novato to San Rafael is likely to suffer heavy damage.

Access to the Bay Area from Stockton would be disrupted by bridge and ground failures west of a line between Concord and Pleasanton. No stub tracks would be available for closer approaches to the Bay Area. The SP line between Pleasanton and Concord might survive, though some bridge damage is likely. Access from the south would also be severely restricted. The SP coast line would likely be intact to Santa Cruz and Morgan Hill, but not further north. The surviving railroad network is illustrated in Exhibit 27.

Yard and terminal facilities would be severely restricted. The major Bay Area terminals would be inaccessible. Facilities at the ends of usable track are limited. The most extensive facilities would come from an imaginative use of industrial sidings in the Pittsburg-Martinez area. Some facilities are available in Livermore and Pleasanton. The coast line could use yards and sidings in Salinas, Watsonville and perhaps Santa Cruz.

Outside of the Bay Area, interstate rail traffic could continue. The major north-south lines in the Central Valley would not be affected. The SP's principal classification yard at

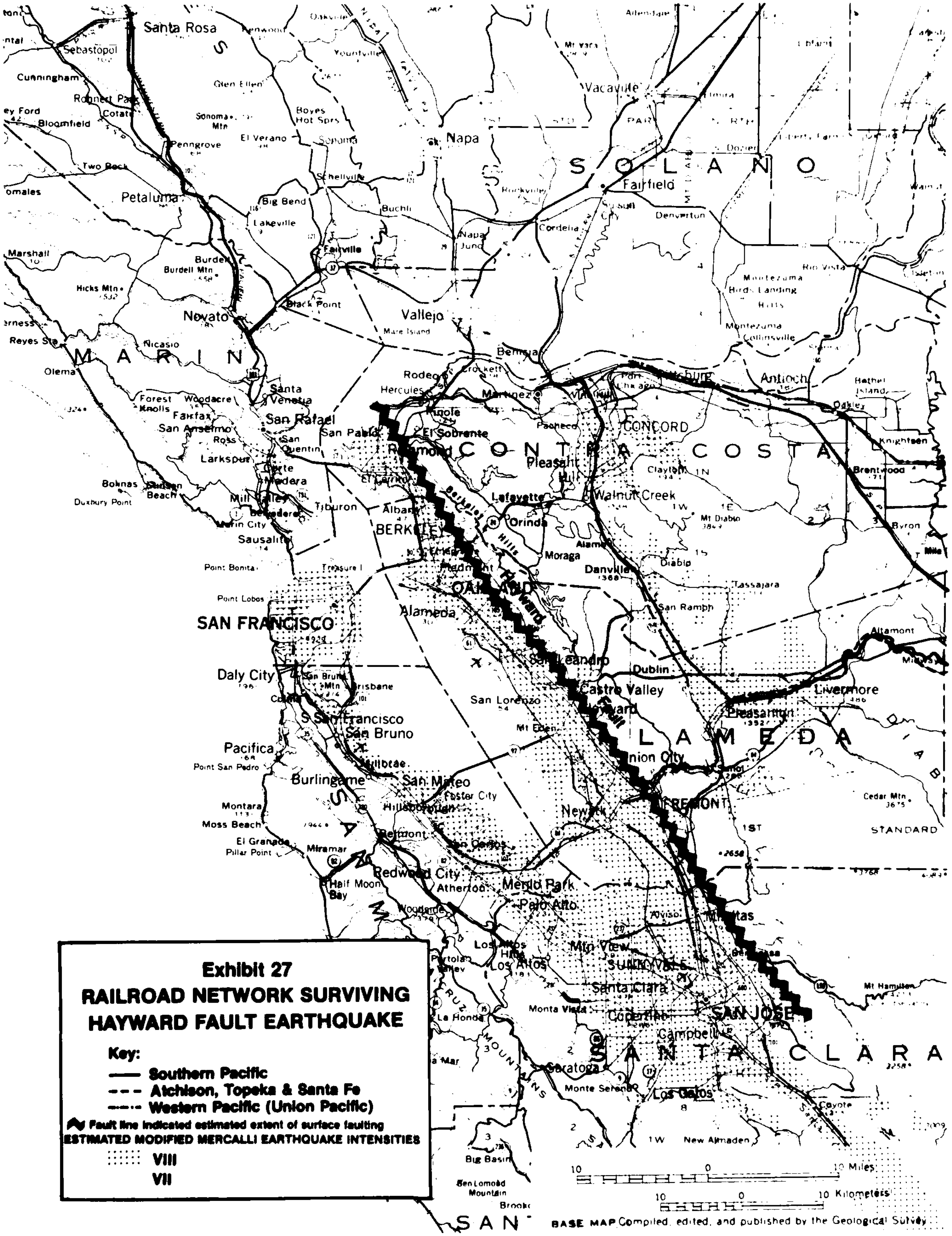


Exhibit 27
RAILROAD NETWORK SURVIVING HAYWARD FAULT EARTHQUAKE

Roseville could continue to function. Coastal communities would, however, feel the impact. The coastal area south of San Francisco could continue to receive service from Los Angeles. The north coastal area would be isolated, but container or trailer-on-flat-car service could be provided, transferring from rail to highway at Roseville or Stockton.

Post-earthquake railroad capability would be limited by yard and terminal capability. Temporary terminals could handle two to four 100-car trains per day. Under emergency conditions, it may be advantageous to operate much shorter trains, perhaps five to 20 cars each, to more effectively use the limited terminal capability. These short trains could be prepared at Sacramento, Stockton and Salinas so that long haul railroad efficiency would not be compromised.

When planning repairs, first priority should be given to re-establishing service to the Bay Area. The line that could be most promptly repaired is the line from the south between Morgan Hill and San Jose. Reopening of yard facilities would add greatly to the terminal capacity. From San Jose, repair work could focus on opening routes to both the East Bay and the West Bay. This would require filling after ground failure and bridge repair. Southern access to the Bay Area would be awkward and inefficient because all traffic would need to be routed via Los Angeles. Nonetheless the southern route could be repaired much more quickly than the routes from the east. Bridge damage and roadbed disruption where lines cross the Hayward fault could require months to repair.

PIPELINE TRANSPORTATION

Although major supply pipelines are relatively hard, both natural gas and petroleum pipelines that serve the San Francisco Bay Area cross the Hayward fault, where they might be subjected to considerable stress. Pipelines are most susceptible to damage at

fault breaks and at locations where differential settlement occurs. In the absence of detailed geological data, locations of ground discontinuities can only be approximated.

Natural Gas Pipelines

Three of the four pipelines that supply natural gas to the Bay Area cross the Hayward fault (Exhibit 7). Two of these are routed south of Niles Canyon near the end of the expected fault. The third passes south of Crockett near the other end of the fault. There is a possibility that one or more of these pipelines might survive the earthquake at the fault. The fourth pipeline, which supplies Marin County and the north coast is clearly out of the fault zone. The two northern pipelines, however, traverse considerable distances of poor soil in which differential settlement could cause serious damage. Cross connecting pipelines east of Livermore are likely to remain intact.

Supply lines to Bay Area communities traverse poor soil where differential settlement could cause damage. The north-south lines (2) along the East Bay are both near the Bay where soil is poor and variable. One of the West Bay lines follows the Bay shore with its poor soil; the other is laid down the peninsula near the San Andreas fault. The latter line would likely survive an earthquake on the Hayward fault. San Rafael and southern Marin County are served by a line that traverses questionable soil near Novato, San Rafael and Corte Madera.

The pipeline terminals are located in the East Bay. The one near Crockett is close to the fault. Others near San Leandro, Newark and Alviso are on or near poor soil. All can be expected to sustain substantial structural damage. One can only speculate whether expander, piping and valve damage would occur. It seems likely that the Crockett terminal would be out of action. One would hope that the Newark terminal might survive because of its strategic location.

Storage facilities in the San Francisco East Bay would also suffer. Holders are located on questionable soil that would be subject to high earthquake intensities (R-F IX). The underground storage near San Rafael has a good chance of survival.

Natural gas supply after a major earthquake on the Hayward fault is a questionable matter. One could expect at least one supply pipeline from the east to survive. Distribution to the Bay Area population centers would be spotty. San Francisco and parts of the East Bay might be supplied. Marin County supply is possible because earthquake intensities on the poor northbay soil might not be higher than R-F VII.

Elsewhere in California, natural gas pipelines would not be damaged. Normal service could continue.

Petroleum and Petroleum Product Pipelines

Two of the six refineries serving the Bay Area (Union and Pacific) are very close to the north end of the Hayward fault. The other four are not far distant. Therefore, one might reasonably expect serious damage to most or all of the refineries. If all refineries are out of service, the continued supply of crude petroleum would be of little concern.

The crude pipelines have a better chance for survival than do the refineries that they serve. The lines serving the Shell, Tosco and Exxon refineries stop short of the fault. Except for a questionable Sacramento River Crossing for the line serving Exxon all have a good chance for survival. The pipelines serving Union and Chevron cross the fault near its north end. Some damage should be expected. The likelihood of complete rupture would depend on the condition of the ground at the fault and the nature of the faulting. Contingency plans should avoid depending on petroleum supply and refining in the Bay Area.

Petroleum product pipelines are more vulnerable than crude lines. All major product lines cross the Hayward fault where, because of their smaller size, they are more susceptable to damage

than crude lines. The transbay lines that serve the San Francisco airport would be subject to damage from liquifaction and differential movement. They may also be damaged at terminal connections because of poor soil under the terminals. Thus product lines in the Bay Area should not be counted on.

Elsewhere in California, petroleum and petroleum product pipelines are not likely to be damaged. Normal service could continue.

AIRPORTS

A major earthquake on the Hayward fault would cause approximately the same airport damage as an earthquake on the San Andreas fault. The principal airports in the Bay Area would suffer runway damage due to liquifaction, pavement buckling or differential settling. These would include San Francisco and Oakland International airports, Alameda Naval Air Station and Hamilton Field. Ground access to these airports would be difficult or impossible. San Jose Municipal Airport and Moffett Naval Air Station would likely suffer runway and control tower damage, but may be able to support limited post-earthquake air operations. If this were the case, it would greatly help emergency supply to the peninsula area. Because of the extent of damage, surviving airports could best support military aircraft like the C-141 and C-130 that are designed to operate on poor quality runways.

High volume air traffic for the Bay Area would need to use Travis Air Force Base which should survive the earthquake intact. This large facility could support high volume air freight and evacuation activities. Access to and from Travis would be difficult.

Several general aviation airports can also be expected to survive the earthquake. Buchanan field in Concord is a marginal candidate as is Hayward airport. Both are likely to suffer some damage. Airports at Half Moon Bay and Santa Rosa could be expected to fare better. Outside the Bay Area, a large number of serviceable

general aviation airports are available. These could be used as basing points for helicopter delivery to more damaged areas.

WATERWAYS AND PORT FACILITIES

A major earthquake on the Hayward fault would inflict serious damage to port facilities; particularly those in the East Bay. The Port of Oakland's facilities in the Inner and Outer harbor areas could expect serious damage. Ground bearing failure, liquifaction and differential settlement would likely topple some gantry cranes, distort track, expose bulkheads, disrupt access roads and damage containers in yard storage. Damage to port facilities in Richmond, San Leandro and Crockett/Martinez would be similar.

Across the Bay, damage would be less severe. San Francisco's Embarcadero piers are likely to survive, as they did in 1906. This resource could be vital to supporting survivors in San Francisco. The San Francisco Belt Railway might be damaged beyond immediate use, but emergency access roads could be built in less than one day. Elsewhere in the West Bay, damage would be comparable to that experienced in Oakland. The San Francisco container terminal is likely to be damaged, and the Port of Redwood City would be closed by channel blockage.

Outside of the Embarcadero, the closest available port facility would probably be Port Chicago. However, this facility would be inaccessible if the SP's Benecia Bridge were stuck in the closed position. Repairs to this bridge are likely to be lengthy and damaged movements both difficult and perilous. Temporary port facilities would need to be constructed at Benecia, Vallejo or elsewhere where there was access to land transportation and available passage to the Bay.

DAMAGE OVERVIEW

Post-earthquake transportation in and about the Bay Area is likely to be extremely limited. With some repair work, limited highway transportation could be available to the San Francisco Peninsula, San Jose, Contra Costa County and northern Marin County. Other areas, particularly the East Bay, would be accessible only by water and then only through temporary port facilities. Railroad service would terminate east of the Oakland hills, south of San Jose and at Fairfield. Rail traffic would need to move by highway or water from these or adjacent points. Air transportation would be similarly constrained. Limited emergency supplies could be moved by military aircraft or helicopters to several Bay Area points; but large volume traffic would need to be routed to Travis A.F.B. for forwarding by highway or water.

Post-earthquake transportation would benefit immeasurably from the construction and operation of a number of emergency intermodal terminals. Rail/highway terminals at Fairfield and Morgan Hill could be used to forward emergency material to Marin County and the San Francisco Peninsula. Rail/water and air/water terminals on the Sacramento River would support water movement to the San Francisco Embarcadero and to the East Bay. These latter terminals may be essential to recovery and evacuation in the East Bay.

The overall picture that emerges is not pretty, but neither is it hopeless. Cooperation, coordination and joint efforts can provide the necessary post-earthquake transportation. However, the analysis underscores the need for contingency plans to assure that energies are constructively directed when the need is great.

VI. 8.3 MAGNITUDE EARTHQUAKE ON THE SOUTH SAN ANDREAS FAULT

Although an 8.3 magnitude earthquake on the South San Andreas fault has an historical precedent in the 1857 Ft. Tejon earthquake, there were essentially no transportation facilities in Southern California in 1857. No railroads existed; roads were wagon trails at best; and port facilities were crude. Such structures as did exist were severely shaken and unreinforced masonry buildings in and about Ft. Tejon were destroyed. Estimates of earthquake damage in Southern California must be taken from more recent earthquakes that did not include slippage on the San Andreas fault. From a transportation perspective, the most useful information comes from the 1933 Long Beach, 1952 Tehachapi and 1971 San Fernando earthquakes. These events provided information on ground failure and on the types of transportation damage that results from ground failure.

The South San Andreas fault earthquake is expected to cause less damage to transportation facilities than any of the other three California earthquake scenarios that were studied. Nonetheless, the San Andreas fault crosses major transportation arteries between Northern and Southern California and between Southern California and the east. As a result, the damage likely to occur can have important impacts on the survival and recovery capability of the Los Angeles Metropolitan Area. Damage to transportation facilities is most likely to occur in the mountains through which the San Andreas fault passes. These mountains separate the coast from the Central Valley and the Mojave Desert.

This chapter presents the results of the analysis. The method of analysis is the same as that described in Chapter IV for an earthquake on the North San Andreas fault.

HIGHWAY TRANSPORTATION

Damage to the highway bridges and roadbeds caused by an earthquake on the southern end of the San Andreas fault would be difficult to repair because of the mountainous terrain. Limited routes through the mountains restrict the available detours. Emergency detours are likely to be difficult to construct. Slide clearance would be slow. As a result post earthquake intercity traffic would be severely affected.

Structural Damage to Bridges

Structural damage to bridges is likely to extend from the mountains north of San Louis Obispo to the vicinity of San Bernardino. In the north, bridges on highways 41 and 46 near the fault are likely to be seriously damaged. The loss of these bridges would interrupt traffic between San Luis Obispo and the Central Valley; however, these are not major routes and support only a modest amount of traffic. Analysis of the bridge sample suggests that the bridges on adjacent U.S. 101, while subject to lesser damage, have a high enough expectation of damage that U.S. 101 is not likely to be available north of San Luis Obispo. South of San Luis Obispo, some damage should be expected as far as Santa Barbara, but it should be possible to keep the highway open.

Further south, the damage is likely to have greater consequences. Bridges are likely to be damaged on Interstate 5 near Bakersfield and in the Tejon Pass area. Bridges would also be damaged on parallel routes (e.g., 166 and 14) that could otherwise be potential detours. Bridges on Interstate 15 and U.S. 395 would be damaged where they cross the San Gabriel Mountains north of San Bernardino. Potential detours around these obstacles would also be denied by bridge damage on routes 18 and 38.

Major bridge damage in the Los Angeles Basin would be confined to highways near San Bernardino and to the routes nearest to the San Gabriel Mountains. Bridges on routes 30, 66 and Interstate 10 would be severely damaged in the western outskirts of San Bernardino

and west toward Upland. Elsewhere bridge damage would be minor. Emergency repairs could be quickly accomplished and most bridges could be restored to service with a few hours work.

Exhibit 28 summarizes expected bridge damage on the highway route segments that are most threatened by a south San Andreas fault earthquake. For each route segment, it also lists the probability that all bridges would survive sufficiently well to remain in at least limited service. Of the 12 route segments listed in Exhibit 28, eight would have bridge survival probabilities of less than 0.5 and are judged unavailable after the earthquake. Of these segments, four cross the San Gabriel mountains; one is a mountain crossing extended to San Bernardino, one crosses the coast range near San Luis Obispo, and the other two are in the alluvial valley at the foot of the San Gabriel Mountains. The loss of these segments would greatly disrupt both north-south and east-west intercity highway traffic.

Ground Failure

Ground failure is likely to cause considerable highway damage in the alluvial deposits on the west side of the Central Valley, in the San Gabriel Mountains and in the alluvial plain south of them. All of the highways that cross the San Gabriel, Sierra Madre and La Panza mountains cross the San Andreas fault and are likely to be severely displaced by fault movement. Thus, highways 2, I5, 14, I15, 39, 46, 58 and 166 are likely to be closed after the earthquake. The long fill by which I5 ascends to Tejon Pass from the north is likely to fail. Less spectacular failures can be expected north toward Bakersfield and beyond. Many slides could be expected in regions of high earthquake intensity around the fault. There is likely to be roadbed failure and considerable blockage. Slides around San Fernando and on the south slopes of the San Gabriel Mountains are likely to damage and block I210 and route 66. Failures of alluvial soil in the San Bernardino corridor will damage routes 30, I10 and 60. Most major highways in San

EXHIBIT 28

PROBABILITY THAT BRIDGES ON HIGHWAY ROUTE SEGMENTS WOULD SURVIVE SOUTH SAN ANDREAS FAULT EARTHQUAKE

Route Segment			Supporting bridges likely to be damaged	Bridge spans		Probability none damaged
Hwy No	From Hwy	To Hwy		Under Hwy	Over Hwy	
I5	58 (Button Willow)	99 (Wheeler Ridge)	1	2	4	0.66
I5	99 (Wheeler Ridge)	14 (San Fernando)	4	8	6	0.32
I10	I15E (San Bernardino)	I15 (Ontario)	14	27	19	0.14
I10	I15E (San Bernardino)	60 (Beaumont)	12	21	11	0.24
14	58 (Mojave)	I5 (San Fernando)	9	9	11	0.22
I15	18 (Victorville)	395 (Hesperia)	2	4	8	0.54
I15	395 (Hesperia)	I15E (Devore)	4	8	11	0.24
I15E	I15 (Devore)	66 (San Bernardino)	5	10	12	0.30
I15E	66 (San Bernardino)	I10 (Colton)	5	10	10	0.44
99	58 (Bakersfield)	I5 (Wheeler Ridge)	1	2	1	0.77
395	58 (Kramer Jc.)	I15 (Hesperia)	1	2	3	0.69
101	1 (Castroville)	1 (San Luis Obispo)	9	14	8	0.45

Bernardino would be damaged or blocked. Severe damage is likely to extend almost to Riverside.

Ground failure and slides can be expected to prevent post-earthquake use of the following highway route segments:

Highway	Between Highway	and Highway	Segment denied by bridge failure
101	1(San Luis Obispo)	1(Castroville)	Yes
I5	152(Las Banas)	58(Button Willow)	No
I5	58(Button Willow)	99(Wheeler Ridge)	No
I5	99(Wheeler Ridge)	14(San Fernando)	Yes
I210	I5/14(San Fernanco)	11(Pasadena)	No
I210	11(Pasadena)	I605(Duarte)	No
I210	I605(Duarte)	66(Glendora)	No
I210	66(Glendora)	I10(Pamona)	No
I10	I210/57(Pomona)	I15(Ontario)	No
I10	I15(Ontario)	I15E(San Bernardino)	Yes
I10	I15E(San Bernardino)	60(Beaumont)	Yes
66	I210(Glendora)	I15(Fontana)	No
66	I15(Fontana)	I15E(San Bernardino)	No
I605	I210(Duarte)	I10(El Monte)	No
I15	18(Victorville)	395(Hesperia)	No
I15	395(Hesperia)	I15E(Devore)	Yes
I15	I15E(Devore)	66(Fontana)	No
I15	66(Fontana)	I10(Ontario)	No
58	I5(Button Willow)	99(Bakersfield)	No
58	99(Bakersfield)	14(Mojave)	No
99	152(Chowchilla)	58(Bakersfield)	No
385	58(Kramer Jc.)	I15(Hesperia)	No

Of the 22 route segments, five have already been judged unavailable due to bridge damage. Some of the remaining routes could be re-opened by clearing slides, filling slumps and providing other temporary repairs. However, because of the magnitude of the problem, and limited repair equipment and crews, emergency repairs can be expected to take a long time.

Surviving Highway Network

If one examines a statistical tabulation of earthquake damage to the highway network, the result is not alarming. Of the 109 highway route segments serving Southern California, 26 or 24 percent are expected to be out of service as a result of the earthquake. One might logically expect that adequate mobility could be provided

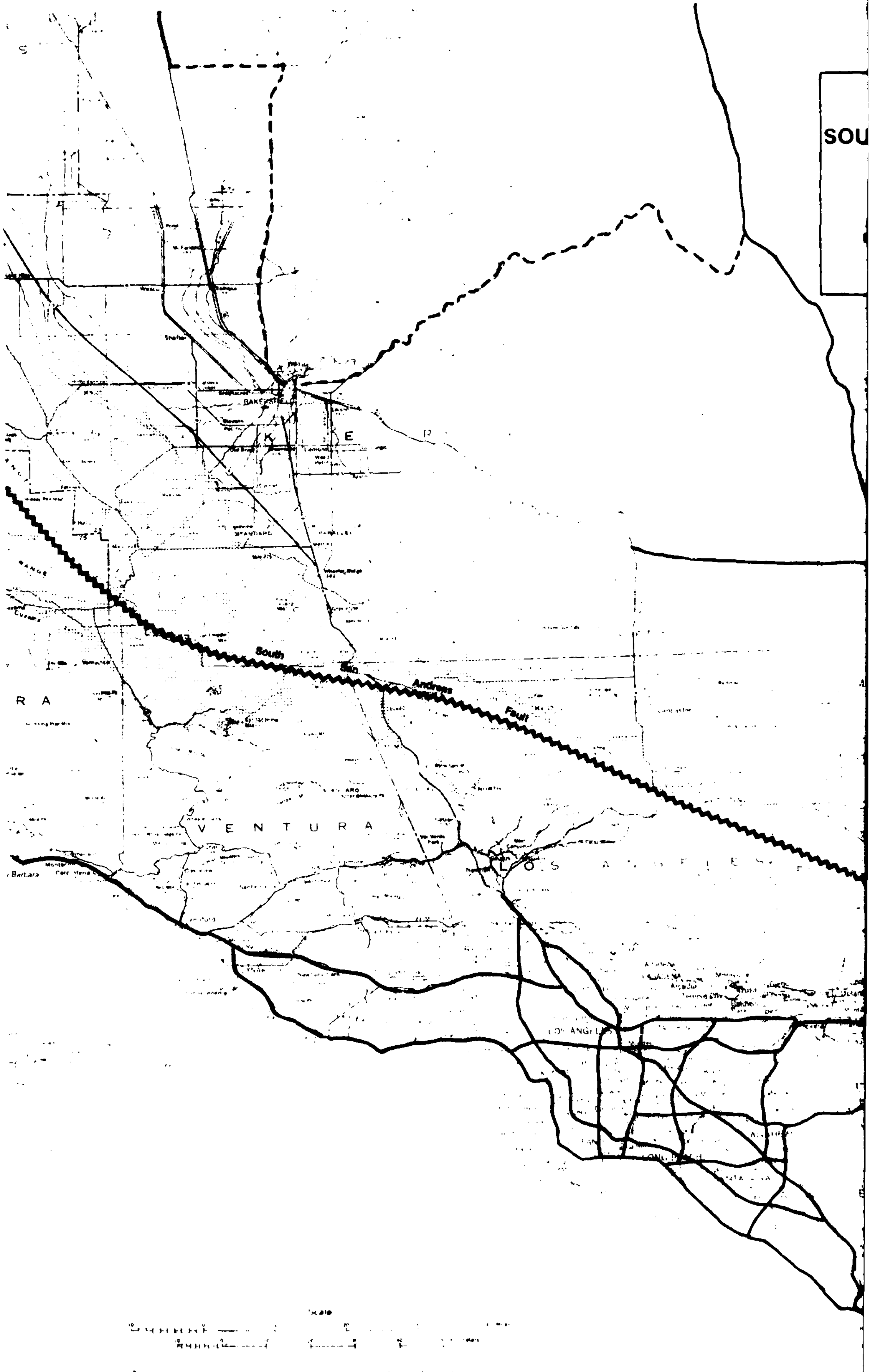
by the surviving route segments. However, an examination of the surviving route segments illustrated in Exhibit 29 suggests that there may be serious problems. A number of important intercity highway links would not be available to handle post-earthquake traffic.

Major north-south routes through the Central Valley would be unusable south of Delano and Kettleman City. This loss would eliminate the major north-south traffic arteries that serve Southern California. This matter is further complicated by the loss of U.S. 101 north of San Luis Obispo. This loss effectively limits intrastate north-south traffic to State Route 1, a two-lane road along the coast which is in good condition but has many tortuous curves. Truck speeds along this route are not likely to average more than 50 kph. North of the Delano-Kettleman City line traffic could move normally. Access to Bakersfield could be provided by detours or emergency routes using State Route 65 or State Route 178 (if it is not closed in the canyon by slides).

In addition to State route 1, access to Southern California is likely to be available via U.S. 395. This route connects with major east-west routes in the Reno, Nevada area. U.S. 395 cannot give direct service to Southern California because it would be blocked between Kramer Junction and San Bernardino. A detour is likely to be available via Barstow and Palm Springs using State Routes 247 and 62.

Access to Southern California from the east is available via Interstate 10 and Interstate 8. Interstate 10 would be serviceable to Riverside, but from there, traffic would need to detour via State routes 60 or 91. Interstate 8 terminates in San Diego. From there, traffic could be routed north via I15 or I5.

Traffic in the Los Angeles area could proceed normally except for communities along the south side of the San Gabriel Mountains from San Fernando to San Bernardino. Emergency routes would need to be established to serve these communities from the surviving network to the south. These routes could use surface routes after



SOU
BAKERSFIELD
South San Andreas Fault
VENTURA
LONG BEACH
Scale

10/2

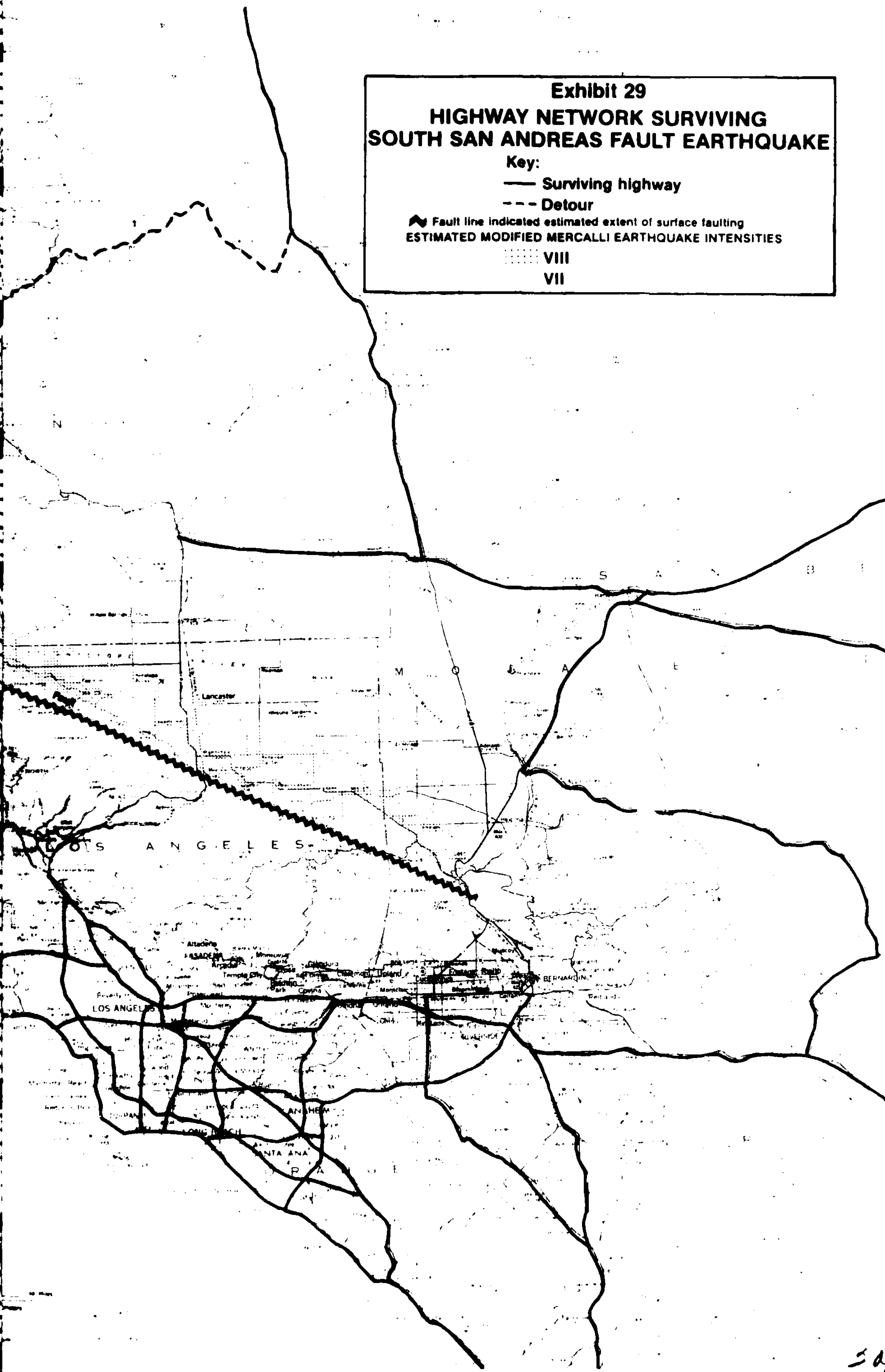


Exhibit 29
HIGHWAY NETWORK SURVIVING SOUTH SAN ANDREAS FAULT EARTHQUAKE

debris clearance on arterial streets that are not blocked by fallen overpasses.

Post Earthquake Highway Capacity

The impact of the earthquake on post earthquake highway capacity can best be expressed in terms of the number of intercity highway lanes available to serve the Los Angeles area. The following tabulation lists pre- and post-earthquake lane availability as measured by lanes supporting inbound traffic only:

	Number of one-way lanes	
Route No.	Pre-Earthquake	Post-Earthquake
U.S. 101 from north	2	1
I5 from north	3	0
SR14	2	0
I15 from north	3	0
I10	3	3
I15 from south	3	3
I5 from south	3	3

This listing suggests that slightly more than half of the pre-earthquake capability would remain. This is not quite true because both I15 and I5 approaching from the south would be fed by I8. As a result, seven of 16 lanes would remain open and several of these would involve reasonably long detours. Nonetheless, it appears that adequate highway capability would survive to meet emergency needs and to support rebuilding on a priority basis.

Post-earthquake highway repairs should focus on opening a route from the north. This would be a problem because of the extensive damage to highways in and near where they cross the fault. There is no clear choice of highways. A survey should be conducted and energy focused on a single route. In the San Luis Obispo area, attention should be focused on reopening U.S. 101 between San Luis Obispo and King City. This work would reestablish a major north-south route and eliminate the tedious detour via State route 1.

RAILROAD TRANSPORTATION

Railroad lines leading to Southern California would also be severely damaged by a major earthquake on the south San Andreas fault. Railroads, roughly paralleling highways, cross or come near the fault for all major routes to the Los Angeles area except for the Southern Pacific (SP) line from Yuma to Colton. Railroad lines crossing the fault are likely to be severely disrupted, with track twisted and roadbeds displaced. Landslides are also likely to be a problem. Elsewhere bridge and ground failures could severely damage railroad route segments.

Structural Damage to Bridges

Railroad bridges are expected to be damaged on 17 of the 58 railroad route segments that serve Southern California. The affected segments are listed in Exhibit 30, together with the probability that all bridges on each route segment will survive. Severe damage can be expected to bridges in the San Gabriel Mountains where earthquake intensities would reach Rossi-Forel IX. Bridge piers and abutments can be expected to shift causing spans to be weakened and dropped. Thus the Santa Fe (ATSF) route segment between Barstow and San Bernardino has only a 0.03 probability of survival. The SP line from Palmdale to San Bernardino can also expect heavy damage.

The SP line between Palmdale and Saugus has only four bridges, all subject to R-F IX intensity. Even so, with the small number of bridges, the probability of survival is greater than 0.5. This line also has two tunnels near the fault that are subject to slides at tunnel portal and internal damage to the lining. As a result, one should not count on the survival of this route segment.

A number of route segments on the alluvial plain south of the San Gabrial Mountains have a low likelihood of survival. The ATSF line between San Bernardino and Los Angeles has 41 bridges likely to be subjected to R-F VIII or higher. The probability of this line's survival is very low--0.03. The roughly parallel SP line

EXHIBIT 30

PROBABILITY THAT BRIDGES ON RAILROAD ROUTE SEGMENTS WOULD SURVIVE A SOUTH SAN ANDREAS FAULT EARTHQUAKE

Rail Road	From	To	Supporting bridges likely to be damaged	Bridge spans Under RR	Bridge spans Over RR	Probability no spans damaged
ATSF	Barstow	San Bernardino	15	33	3	0.03
ATSF	San Bernardino	Los Angeles	41	64	12	0.03
ATSF	San Bernardino	Atwood	2	8	1	0.64
SP	Oxnard	Burbank	7	18	4	0.35
SP	Palmdale	Saugus	4	5	2	0.53
SP	Saugus	Burbank	7	12	2	0.51
SP	Palmdale	San Bernardino	12	16	2	0.17
SP	San Bernardino	Colton	5	23	3	0.28
SP	Mojave	Palmdale	3	5	2	0.53
SP	Burbank	Los Angeles	3	3	1	0.83
SP	San Bernardino	El Monte	7	15	3	0.42
SP	Chatsworth	Burbank	6	16	4	0.38
SP	Oxnard	Castroville	12	17	3	0.38
SP	Oxnard	Saugus	14	32	6	0.15
UP	Riverside	Pomona	9	29	4	0.20
UP	San Bernardino	Riverside	4	8	3	0.61
UP	Pomona	City of Industry	6	33	5	0.16
UP	City of Industry	Whittier Jc.	1	1	0	0.95

between San Bernardino and El Monte is also likely to be out of action because of bridge failures. The ATSF's more southerly route to Atwood has a better than 50 percent chance of bridge survival. However, the Union Pacific route between Riverside and Pomona is likely to be lost. The long bridge across the Santa Ana River is particularly vulnerable. The UP lines between Riverside and the City of Industry are also likely to suffer extensive bridge failure. The SP line between Colton and Burbank is likely to be damaged as are the extensive yard and shop facilities in Colton.

The SP coast line between Burbank and Oxnard is likely to suffer heavy bridge damage through ground failure at abutments and pier shifting. The parallel route between Burbank and Chatsworth (near San Fernando) would also suffer considerable damage. The three tunnels on the Oxnard-Burbank line would likely survive. There may be some blockage at tunnel portals, but this could be quickly cleared.

Further north, extensive bridge damage should be expected on the coast line where the route crosses the Coast Range. This damage would occur north of San Luis Obispo, near Atascadero and Paso Robles.

Using a criterion of 0.5 probability of survival, ten of the 17 route segments listed in Exhibit 30 are expected to be lost. In addition, the SP line between Saugus and Burbank is likely to be denied as a result of both tunnel and bridge failures.

Ground Failure

Railroad lines in the mountains are subject to slides and rock falls that can damage and block the track and its underlying structure. Ground failure under the roadbed can also cause damage wherever poor ground structure is encountered. Estimates of ground failure are uncertain because of the paucity of good soil data; however some statements can be made with reasonable confidence. In areas of high earthquake intensity, alluvial soil can be expected to fail and steep embankments can be expected to slide. These conditions are likely to occur on the following railroad route segments:

Railroad	Route segment	Route segment lost due to bridge failure?
SP	Colton-El Monte	No
SP	Burbank-Saugus	No
SP	Oxnard-Castroville	Yes
SP	Saugus-Palmdale	Yes
SP	Mojave-Bakersfield	No
SP	Bakersfield-Famoso	No
SP	San Bernardino-El Monte	Yes
SP	Palmdale-Mojave	No
SP	Palmdale-San Bernardino	Yes
ATSF	Bakersfield-Corcoran	No
ATSF	Bariton-San Bernardino	Yes
ATSF	San Bernardino-Los Angeles	Yes
ATSF	San Bernardino-Atwood	No
UP	City of Industry-Whittier Jc.	Yes

Intense ground shaking, rockslides and failure of fills are likely to close the mountain passes in the San Gabriel Mountains. The SP line through the Soledad pass crosses the San Andreas fault just south of Palmdale. Extensive slippage and shaking would cause extreme damage between Acton and Palmdale and lesser damage elsewhere. The ATSF line through Cajon Pass crosses the fault just southeast of the expected limit of surface faulting. Even so, extensive damage to this line should be expected. Further north, the SP line through Antelope Valley, Palmdale to Mojave, would be subjected to intense shaking that would likely cause track disruption and differential fill settlement.

Railroad lines on the plain south of the San Gabriel Mountains would also be subject to extensive damage. Damage around San Bernardino would be particularly heavy. The ATSF and SP lines between San Bernardino and Glendora would be extensively damaged. The lines between San Bernardino and Riverside are also subject to damage. The SP line east of Colton through the San Gorgonio Pass is likely to be blocked by highway bridges, if the roadbed survives. The ATSF route down the Santa Ana Canyon (San Bernardino-Atwood) is likely to be lost due to local ground failure. The SP and UP lines between Whittier and Diamond Bar would also be subject to local failure.

The SP coastline would probably be isolated by ground failures in the San Fernando Valley and the Santa Clara Valley as well as in the Cuesta Pass north of San Luis Obispo. The main line between Burbank and Oxnard would be damaged by intense ground shaking in the Simi Valley, liquifaction in the Oxnard plain and intense shaking in the Western San Fernando Valley. Local ground failure and liquifaction would close the Santa Clara Valley line which serves as a secondary connection between Oxnard and Saugus. The line through Cuesta Pass would be closed by rock slides and ground failure under fills and bridge abutments.

Of the 14 route segments on which ground failure is expected, seven have already been eliminated because of bridge failure. Three more are listed in Exhibit 30 as subject to bridge damage but the probability of all bridges surviving is greater than 0.5. The remaining four segments have lines over alluvial material near Bakersfield where intensities are likely to reach R-F VIII or IX.

The Surviving Railroad Network

A major earthquake on the south San Andreas Fault is likely to isolate the Los Angeles basin from railroad service (See Exhibit 31). Twenty-one of the 59 route segments that serve Southern California would be unavailable for post-earthquake service. The 21 segments include all major connections with the north--the SP coast line, the SP Soledad Pass line and the ATSF Cajon Pass line. All of these lines would require extensive repairs before service could be restored. The SP line from Yuma, Az, would be open as far as the outskirts of San Bernardino; but there would be no available connections to other lines.

The only railroad access to Los Angeles would have to come via San Diego using the San Diego and Eastern Arizona and the Tijuana and Tecate. Both of these lines are in poor condition. Some repairs are under way, but it is unlikely that they could ever support more than two or three trains per day. Some rail traffic might be brought to the Los Angeles via the SP Yuma to San Bernardino main

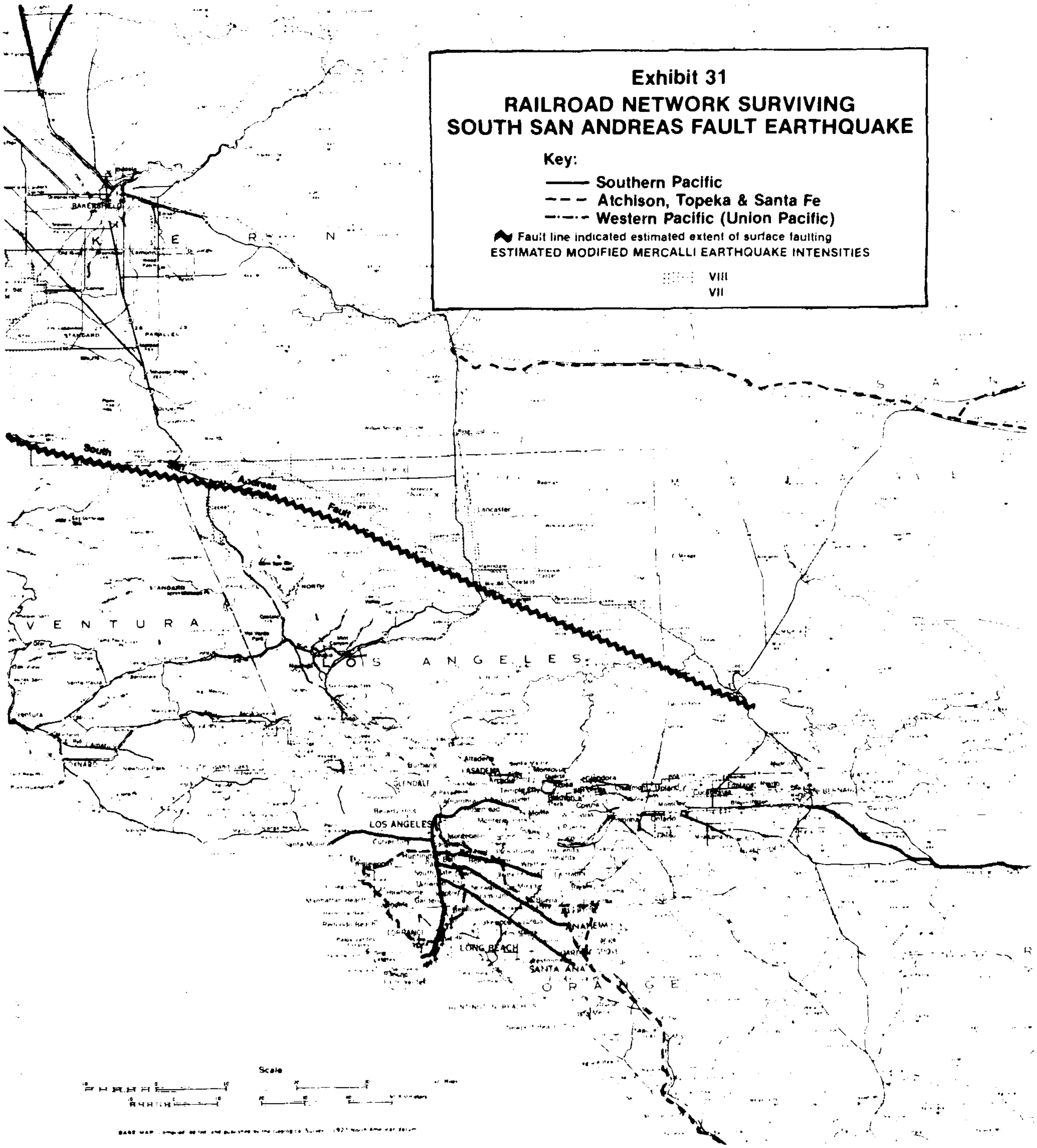


Exhibit 31
RAILROAD NETWORK SURVIVING
SOUTH SAN ANDREAS FAULT EARTHQUAKE
Key:
Southern Pacific
Atchison, Topeka & Santa Fe
Western Pacific (Union Pacific)
Fault line indicated estimated extent of surface faulting
ESTIMATED MODIFIED MERCALLI EARTHQUAKE INTENSITIES
VIII
VII
K E R N
BAKERSFIELD
South San Andreas Fault
V E N T U R A
L O S A N G E L E S
LOS ANGELES
ANAHEIM
LONG BEACH
SANTA ANA
O R A N G E
Scale

line and transferred to trucks at Beaumont or Palm Springs. Temporary trailer-on-flat-car (TOFC) ramps could be built quickly to facilitate transfers. Unfortunately, terminal facilities at these locations are very limited.

The post-earthquake capacity to serve Los Angeles would be very small--probably no more than five trains per day, including TOFC operations at Beaumont and Palm Springs. This is a dramatic loss from the 120 to 140 trains per day that could enter the Los Angeles area today. Rail shipments would, therefore, need to be severely restricted to the most critical needs.

In rebuilding railroad facilities after an earthquake, attention should focus on reestablishing the SP's main line between Yuma and Los Angeles. This would require a detour around the San Bernardino-Colton area, perhaps via Riverside, and repairs to ATSF and UP lines down and across Santa Ana Canyon. These routes are likely to suffer less damage than other access routes and could be restored most quickly. Restoration of other routes would require months of intense effort, particularly in view of crew and equipment shortages.

PIPELINE TRANSPORTATION

Pipelines serving Southern California follow essentially the same routes as major highways and railroads. As a result, most major pipelines cross the San Andreas fault where surface faulting is expected. Because of their underground locations and high strength, high pressure pipelines may survive severe slippage. Nonetheless, prudent planning suggests that pipeline breaks should be expected where the fault is crossed. Failures should also be expected if connections to compressor or pumping stations are subjected to intense shaking, e.g., R-F IX. Pipelines can be damaged by differential settlement, but survival here is more likely.

Natural Gas Pipelines

Six of the eight natural gas pipelines that serve the Southern California market cross the San Andreas fault at or near expected surface faulting. For planning purposes these pipelines should be presumed to rupture. Pressure actuated cut off valves are likely to minimize gas loss. At the high transmission pressure, there is little danger of fire.

The two surviving lines, owned and operated by Southern California Gas Company, enter the area south of the expected fault break via the San Gorgonio Pass. They pass south of Riverside, where they separate with the more northerly line traversing poor soil in the Riverside-Rosemead area. This line could be subjected to severe stress by differential settlement but seems likely to survive. The more southerly line passes through better ground and would be subjected to less intense shaking. These two lines supply power plants at El Segundo, Redondo Beach, Long Beach and Huntington Beach. They can also be connected to a considerable part of the Los Angeles area's distribution system. These lines are capable of carrying about 25 percent of the pre-earthquake capacity.

The Los Angeles area's four underground storage facilities are also capable of providing emergency supplies of natural gas. These supplies can be expected to last from several days to several weeks, depending on the extent of the damage to the distribution system and on the energy priorities that are established.

Emergency repairs should concentrate on the gas distribution system until such time as the demand exceeds the available supply. These efforts can be directed toward repairing breaks in other supply lines.

Petroleum and Petroleum Product Pipelines

All of the major oil refineries in the Los Angeles area are likely to survive a major earthquake on the South San Andreas fault. Refineries located on poor soil in and near Long Beach might be damaged; but major structures are on pile supported foundations that are likely to survive the expected earthquake intensity.

Crude petroleum supplies need not be short, because all refineries can be supplied with crude brought in by water. This is fortunate because the three major supply lines from San Joaquin Valley producing fields cross the Tejon Pass parallel to Interstate Highway 5. In addition, there are pumping stations near the fault that would surely be damaged. Oil fields within the Los Angeles Basin could continue to produce and to supply local refineries.

Only the crude pipeline routed east via the San Gorgonio Pass would likely survive. Even this line passes through some unstable soil in the Santa Ana River Canyon. Nonetheless, it seems likely to survive.

Petroleum product lines from Los Angeles refineries serve markets in Nevada and Arizona. This line passes through poor alluvial soil before it divides at Colton to separate lines to Nevada and Arizona. The line to Nevada is likely to be ruptured where it crosses the fault near the southern limit of surface rupture. The Arizona line, which is routed via San Gorgonio Pass, is likely to survive.

AIRPORTS

The runways of major Southern California airports are likely to survive a major earthquake on the South San Andreas fault with relatively little damage. Other problems will doubtless complicate flight operations. Loss of electric power could eliminate major flight control equipment. Structural damage to terminal buildings and control towers could make passenger and cargo handling difficult and awkward. Emergency fuel handling procedures may be needed.

The area's major commercial airports--Los Angeles International, Burbank, Ontario, Long Beach and Orange County--could likely remain in at least limited operation. If necessary for emergency supply or evacuation, these could be augmented by military airports. March and George Air Force Bases and El Toro Marine Air Station can all

support major jet aircraft, including C141 and C5A military transports. The U.S. Air Force Plant 42 runways at Lancaster are likely to survive because of soil quality despite an R-F IX intensity that would destroy many buildings. Norton Air Force Base, near San Bernardino, might suffer runway damage because of high earthquake intensity and questionable soil. Los Alamitos Reserve Airfield may also suffer damage due to poor soil. Both military and commercial airfields in Ventura County are on soil subject to liquifaction.

The post-earthquake airlift capacity of the Los Angeles Basin's airports is likely to approach present commercial operations. On clear days losses in runway capacity, due to limited availability of flight control equipment, can be made up by use of supplemental military airports. On days with poor visibility, flight operations would need to be stopped or severely limited. When electric power can be restored, the level of flight operations can be increased. Flight operations can be increased further as emergency repairs are completed.

WATERWAYS AND PORT FACILITIES

The principal ports of Southern California are likely to sustain only minor damage as a result of a South San Andreas Fault earthquake. Poor soil in and about the ports of Los Angeles and Long Beach is liable to cause local failures, but the ports themselves should be able to remain open. Ground access may be impeded by local failures to roads and railroads. There is considerable local concern about the Union Pacific bridge to Terminal Island. The analysis, however, suggests that this bridge would likely stand. Debris clearance may present some problems, but the ports should soon be brought into operation. Loss of electric power could eliminate use of sophisticated cargo handling equipment.

Elsewhere, ports would sustain minor damage. Port Hueneme is expected to survive as well as Los Angeles/Long Beach as are the small ports near Santa Maria and Santa Barbara.

DAMAGE OVERVIEW

The southern end of the San Andreas fault is strategically located to damage almost all surface transportation routes that serve the Los Angeles Basin. Extensive damage would extend from the southern San Joaquin Valley around Bakersfield to San Bernardino and surrounding alluvial deposits. Intercity routes between Los Angeles and San Diego would not be affected. However, further damage would occur in the San Luis Obispo area, severing the principal coastal highway and railway.

Emergency highway routes could be quickly established to serve most, if not all, of the Los Angeles area. These routes would depend on Interstate highways 10 and 8 from the east. Detours would need to be established around San Bernardino and other areas of local damage. When emergency repairs are complete, the highway network could carry about 40 percent of the pre-earthquake capacity. This would be sufficient to meet emergency needs and to support some industrial rehabilitation.

Rail service would be effectively denied to the Los Angeles area. Some intermodal shipments could be transferred to highway carriers near Beaumont or Palm Springs. This activity would add to the burden of the damaged highway network. There is a remote chance that a southern route could be established via the San Diego and Eastern Arizona, the Tijuana and Tecate and the ATSF. However, this route depends on extensive rehabilitation, only some of which is under way. At best the rail network could support five percent of its pre-earthquake traffic.

Pipeline networks are likely to be damaged or ruptured where they cross the fault. Limited alternative routes are available via the San Gorgonia Pass. Surviving pipelines could supply about one fourth of the pre-earthquake natural gas; underground storage could supply more. Distribution networks are likely to be damaged, but lines could probably be kept open to major power plants and to other customers in Los Angeles and Orange County.

The petroleum industry would survive essentially intact. Major refineries would likely shut down for inspection, but they could probably reopen in a few days. Central Valley sources of crude petroleum would be cut off by pipeline ruptures at the fault, but refineries could be supplied by water. Damage to product pipelines may affect Southern Nevada and Arizona; but highway distribution will be possible. It seems likely that emergency energy needs could be met.

Airports and marine terminals are expected to survive almost intact. These could be used for evacuation and for supplying emergency supplies. The immense rebuilding effort would depend heavily on cargo brought in by water.

VII. 7.5 MAGNITUDE EARTHQUAKE ON THE NEWPORT-INGLEWOOD FAULT

Because the Newport-Inglewood fault passes through heavily populated Los Angeles metropolitan area, a 7.5 magnitude earthquake is likely to cause many casualties and widespread destruction to a variety of structures. Experts believe that such an earthquake could cause more casualties and greater damage, as measured in monitary loss, than a much larger earthquake on the South San Andreas fault.

From the transportation perspective, the two Southern California earthquakes are very different. The South San Andreas fault earthquake would cause extensive damage to intercity surface transportation routes--highways and railways--while causing little damage to airports or marine terminals. An earthquake on the Newport-Inglewood fault would produce the opposite results. Damage to surface transportation networks would be local. Most intercity routes would survive with the help of a few detours. In contrast, there would be severe damage to major airports and the two large ports of Los Angeles and Long Beach.

This chapter presents the results of the analysis of impacts that a 7.5 magnitude earthquake on the Newport Inglewood fault would have on transportation facilities. The analytical methods used are the same as those described in Chapter IV for an earthquake on the North San Andreas fault.

HIGHWAY TRANSPORTATION

The highway network serving communities from Culver City and Inglewood southeast to Long Beach and Lakewood would be badly damaged by a Newport-Inglewood earthquake. The greatest destruction

would occur along a narrow band on either side of the fault. However, earthquake intensities of R-F VIII would damage bridges and induce ground failures over a much wider area.

Structural Damage to Bridges

Bridges on 47 of the 109 highway route segments that serve Southern California would be subjected to earthquake intensities great enough to cause structural damage. This suggests the potential for severe damage even though it is confined to a relatively small area.

Most of the 47 threatened route segments listed in Exhibit 32 are short, ranging in length from five km to 25 km. Some of these route segments contain many bridges both supporting the roadway and crossing over it. Others have only a few bridges. The greatest probability of damage that would render a supporting bridge unusable under Rosse-Forel intensity VIII is only about five percent (Exhibit 18). Therefore, with each bridge given independent exposure to potential damage, the route segments with few bridges are likely to survive while those with many bridges are not. The last column in Exhibit 32 lists the probability that all bridges on or crossing the different route segments would survive. These probabilities vary from a low of 12 percent to a high of 90 percent. The distribution is as follows:

Probability of Survival	No. of Route Segments
10-19%	2
20-29	4
30-39	4
40-49	8
50-59	5
60-69	6
70-79	8
80-89	9
90-99	1
	47

With the survival probabilities spread throughout the range, there is no particular value that would divide the route segments into

EXHIBIT 32

PROBABILITY THAT BRIDGES ON HIGHWAY ROUTE SEGMENTS WOULD SURVIVE A 7.5 MAGNITUDE EARTHQUAKE ON THE NEWPORT-INGLEWOOD FAULT

Route Segment			Support	Spans			
Hwy	From	To	Bridge	Under	Over	Prob.	Out
101	1(Oxnard)	405(Sherman Oaks)	7	14	20	0.27	X
101	405(Sherman Oaks)	170/B4(Burbank)	2	4	3	0.74	
101	170/134(Burbank)	I5(Glendale)	19	28	23	0.12	X
1	101(Oxnard)	I10(Santa Monica)	1	2	3	0.82	
1	11(Long Beach)	7(Long Beach)	3	5	2	0.73	
1	7(Long Beach)	22(Signal Hill)	2	4	0	0.81	
1	22(Signal Hill)	39(Huntington Beach)	1	2	0	0.90	
I5	I405(San Fernando)	170(Van Nuys)	1	4	4	0.72	
I5	170(Van Nuys)	134(Glendale)	5	11	10	0.42	X
I5	134(Glendale)	I10(Los Angeles)	21	21	16	0.21	X
I5	I10(Los Angeles)	7(E. Los Angeles)	9	13	10	0.38	X
I5	7(E. Los Angeles)	I605(Downey)	5	10	8	0.47	X
I5	I605(Downey)	39/91(Buena Park)	7	10	9	0.46	X
I5	39/91(Buena Park)	57/22(Santa Ana)	1	2	6	0.75	
I210	I5/14(San Fernando)	11(Pasadena)	7	14	15	0.31	X
I210	11(Pasadena)	I605(Duarte)	1	2	3	0.82	
170	I5(Arleta)	101(Van Nuys)	7	14	5	0.42	X
I405	I10(Santa Monica)	91(Torrance)	11	21	14	0.16	X
I405	91(Torrance)	11(Carson)	1	3	0	0.86	
I405	11(Carson)	7(Long Beach)	1	4	1	0.79	
I405	7(Long Beach)	I605/22(Long Beach)	4	9	8	0.49	X
I405	I605/22(Long Beach)	39(Huntington Beach)	0	0	9	0.76	
I10	1(Santa Monica)	I405(Santa Monica)	6	6	9	0.53	
I10	I405(Santa Monica)	11(Los Angeles)	12	21	9	0.26	X
I10	11(Los Angeles)	I5(Los Angeles)	8	18	2	0.37	X
I10	I5(Los Angeles)	7(Alhambra)	1	2	8	0.71	
I10	7(Alhambra)	I605(El Monte)	4	11	5	0.49	X
60	I5/I10(Los Angeles)	7(E. Los Angeles)	5	10	3	0.55	
60	7(E. Los Angeles)	I605(Whittier)	7	11	7	0.46	X
60	I605(Whittier)	57(Ocarmond Bar)	1	2	2	0.85	
91	7(Compton)	I605(Bell Flower)	6	12	1	0.52	
91	I605(Bell Flower)	I5(Buena Park)	3	6	3	0.67	
91	I5(Buena Park)	57(Anaheim)	2	4	2	0.77	
22	1(Long Beach)	I405(Long Beach)	2	2	2	0.85	
22	I405(Long Beach	I5(Santa Ana)	1	2	4	0.80	
11	I5(Los Angeles)	I10(Los Angeles)	8	16	18	0.25	X
11	I10(Los Angeles)	I405(Carson)	2	4	14	0.53	
11	I405(Carson)	1(Wilmington)	2	5	5	0.66	
7	I10(Alhambra)	60(Monterey Park)	6	6	4	0.65	
7	60(Monterey Park)	I5(E. Los Angeles)	6	6	4	0.65	
7	I5(E. Los Angeles)	91(Compton)	8	12	14	0.35	X
7	91(Compton)	I405(Long Beach)	7	7	7	0.56	
7	I405(Long Beach)	1(Long Beach)	0	0	4	0.88	
I605	I10(El Monte)	60(Whittier)	1	2	2	0.85	
I605	60(Whittier)	I5(Downey)	6	12	6	0.45	X
I605	I5(Downey)	91(Buena Park)	3	6	2	0.69	
I605	91(Buena Park)	I405(Long Beach)	3	6	6	0.61	

logical groupings. If one uses 50 percent or higher probability of survival as the criterion for expecting the post earthquake availability of a highway route segment, then one would expect that 29 of the route segments listed in Exhibit 31 would survive and 18 would not. Thus, use of 17 percent of the highway route segments would be denied because of structural damage to bridges.

Ground Failure

Ground failure that is sufficiently extensive to deny use of highway route segments could be expected along the fault, and in the narrow band adjacent to the fault where intensities of R-F IX are expected. There could also be some ground failure in alluvial plains that are subjected to R-F VIII intensities. Local failures could occur elsewhere but can normally be found around very localized failures.

Ground failure by surface faulting is likely to cause sufficient disturbance to roadbeds to close the following six route segments:

Highway	From Hwy	To Hwy	Failure Expected due to Bridge Damage
1	22(Signal Hill)	39(Huntington Beach)	No
1	39(Huntington Beach)	55(Newport Beach	No
I405	7(Long Beach)	I605/22(Long Beach)	Yes
I10	I405(Santa Monica)	11(Los Angeles)	Yes
22	1(Long Beach)	I405(Long Beach)	No
7	91(Compton)	I405(Long Beach)	No

Of the six route segments that cross the fault, only two have been eliminated from post-earthquake service because of expected bridge damage. Damage would be most extensive along State Route 1 which is on or adjacent to the fault between Long Beach and Newport Beach. The highway is close to the coast where it can be affected by the failure of bluffs and liquifaction of sand in subsoil. It crosses marsh land at Seal Beach where soil failure can also be expected.

The route segments expected to be damaged by high intensity shaking near the fault are the same ones that cross the fault. The

band of R-F IX intensity shaking would add additional destruction due to liquifaction and differential settlements.

The only highways likely to be closed by slides are I210 which has some steep embankments along the foothills of the San Gabriel Mountains and Route 1 where it passes close to the Pacific Palisades. Other route segments constructed on the alluvial soil of drainage areas would be subjected to ground failure and liquifaction. Ground failure outside the fault zone is likely to deny use of the following route segments:

Hwy	From Hwy	To Hwy	Failure Expected due to Bridge Damage ?
1	101(Oxnard)	I10(Santa Monica)	No
1	I10(Santa Monica)	11(Long Beach)	No
1	11(Long Beach)	7(Long Beach)	No
1	7(Long Beach)	22(Signal Hill)	No
1	55(Newport Beach)	I5(San Juan Capistrano)	No
I5	I405(Laguna Hills)	1(San Juan Capistrano)	No
I210	I5/14(San Fernando)	11(Pasadena)	Yes
I405	I5(San Fernando)	101(Sepulveda)	No
I405	I605/22(Long Beach)	39(Hungtington Beach)	No
91	7(Compton)	I605(Bell Flower)	No
7	I5(E. Los Angeles)	91(Compton)	Yes
7	I405(Long Beach)	1(Long Beach)	No
I605	I210(Duarte)	I10(El Monte)	No
I605	I10(El Monte)	60(Whittier)	No
I605	60(Whittier)	I5(Downey)	Yes
I605	I5(Downey)	91(Beren Park)	No
I605	91(Buena Park)	I405(Long Beach)	No
55	I405(Costa Mesa)	1(Newport Beach)	No

Of the nineteen route segments likely to be affected by soil failure, only three are expected to be unavailable because of bridge failure. However, ten of the sixteen segments that were not ruled out by bridge failure can expect some damage as evidenced by their inclusion in Exhibit 32. These ten segments had too few bridges to generate a probability less than 0.5 that all would survive. The most serious damage would affect Route 1 where it is near the coast and I605 which is built on alluvial soil along the San Gabriel River bottom.

In the aggregate, ground failure is likely to remove twenty additional route segments from the post earthquake highway network. These route segments serve the same general area as route segments eliminated because of potential bridge damage.

Surviving Highway Network

The highway network expected to survive an earthquake on the Newport-Inglewood fault would be greatly abbreviated in the Los Angeles area. Of the 109 highway route segments serving the Los Angeles area, 38 are expected to be available to carry traffic in the immediate post-earthquake period. Exhibit 33 illustrates the post-earthquake highway network. Major intercity routes can be expected to survive intact, although many would be interrupted by damage in the Los Angeles area. No appreciable damage is expected on Interstate 15 which could continue to carry major north-south traffic via San Bernardino. Interstate 5 would not fair so well. It is expected to survive north of San Fernando and south of San Clemente. Between these points, there could be extensive damage. Intercity traffic could be routed around Los Angeles via routes 14, 138, I15 and 74 or 76. Highway 101 would be usable from the north as far as Woodland Hills. Detours via surface streets could likely be improvised to provide a connection to I5 at San Fernando. From there, through traffic could follow the I5 detour. Interstate 10 from the east should be usable as far as El Monte. Thus, it could connect with north-south routes at the I15 and I15E interchanges.

Highway access to the damaged areas of Los Angeles, Long Beach and south coastal communities might be difficult. Surface street detours could likely be found to connect surviving route segments with the balance of the highway network. Nonetheless many parts of the metropolitan area would have to be served via surface street detours, some of which might be ten miles long or longer. Individually these might not take long to clear and establish, but collectively, the job would be enormous.

Post-Earthquake Highway Capacity

If one were interested only in the capacity of intercity highways reaching the outskirts of the Los Angeles area, then one could contend that the Newport-Inglewood earthquake intercity highway capacity would not be diminished. However, other views are more

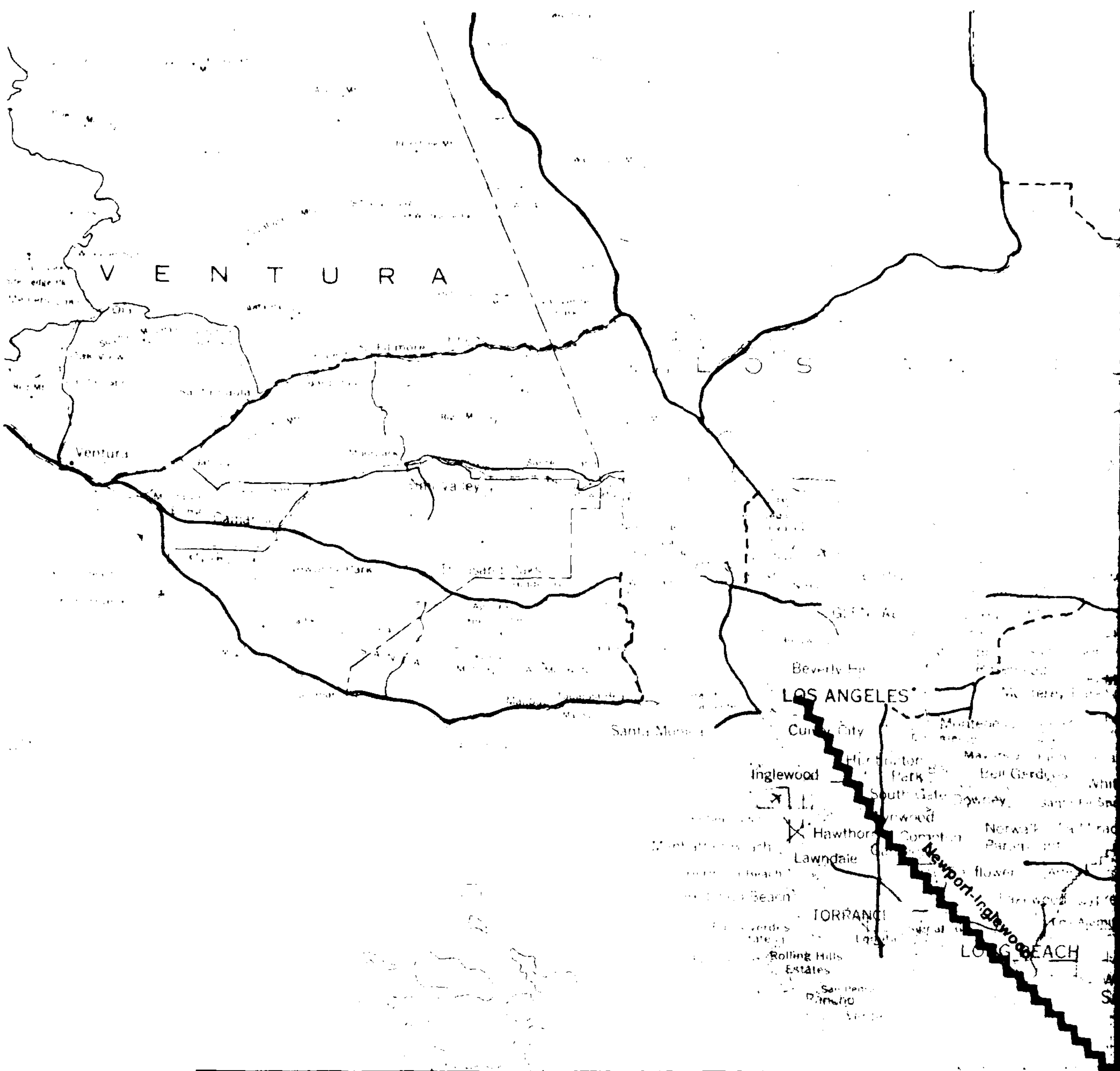
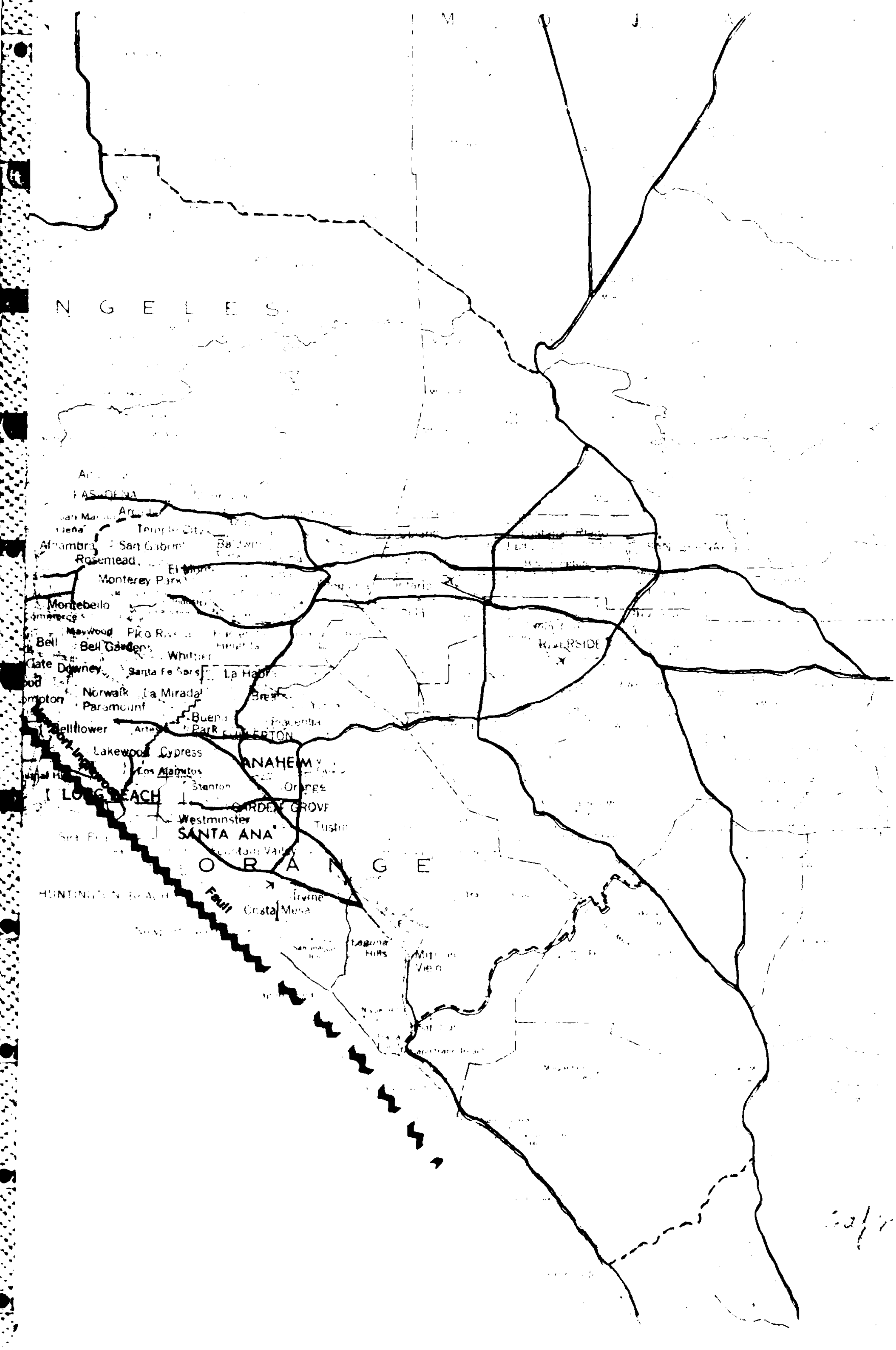


Exhibit 33
HIGHWAY NETWORK SURVIVING
NEWPORT-INGLEWOOD FAULT EARTHQUAKE

Key:
—— Surviving highway
- - - Detour
Fault line indicated estimated extent of surface faulting
ESTIMATED MODIFIED MERCALLI EARTHQUAKE INTENSITIES
VIII
VII

1 of 2

Miles
Kilometers
BASE MAP compiled, edited, and published by the Geological Survey



M O J A
N G E L E S
Arcadia
Temple City
Alhambra
San Gabriel
Rosemead
El Monte
Monterey Park
Montebello
Commerce
Maywood
Bell
Bell Gardens
Pico Rivera
Whittier
Downey
Santa Fe Springs
La Habra
Norwalk
La Mirada
Paramount
Compton
Bellflower
Buena Park
FULLERTON
Lakewood
Cypress
Los Alamitos
ANAHEIM
Stanton
Orange
LONG BEACH
GARDEN GROVE
Westminster
SANTA ANA
Tustin
O R A N G E
Irvine
Costa Mesa
Fault
Laguna Hills
Mission Viejo
RIVERSIDE

illuminating. Consider, for example, pre- and post-earthquake north-south intercity highway capacity. The following tabulation of available lanes indicates that intercity lanes would be reduced by 62 percent.

Route No.	Number of One-Way Lanes Pre-Earthquake	Post-Earthquake
U.S. 101	2	0
I5	3	0
I15	3	3

As a result, intercity traffic would need to be limited so that highway facilities could be used to support emergency needs and the recovery of the damaged area.

Post-earthquake highway repairs should focus on establishing high quality detours to connect Interstate 5 and U.S. 101 with a major east-west highway like I10 or 60. Priority should also be placed on transportation access to coastal areas that are on or near the fault. By far the bulk of the post-earthquake effort will need to be directed toward emergency routes to evacuate and support survivors.

RAILROAD TRANSPORTATION

Damage to the railroad network by a Newport-Inglewood earthquake would be similar to that already described for highways. Major intercity lines would survive outside of the Los Angeles area. Damage would be concentrated on lines near the fault and on bridges and roadways elsewhere that are located on poor soil.

Structural Damage to Bridges

Because of their age, design and construction, railroad bridges are more susceptable to earthquake damage than newer highway bridges, particularly those built to 1971 earthquake standards. Of the 59 railroad route segments that serve Southern California, bridges on 34 of them would be subjected to shaking intensities sufficient to

produce damage (R-F VIII or greater). These route segments are listed in Exhibit 34 together with the number of bridges that might be damaged, including both bridges supporting the railroad and those crossing over it. Treating each bridge independently in accordance with the expected earthqua..e intensity and the bridge's structural characteristics, a probability that all bridges would survive was calculated for each route segment. These probabilities, which are listed in Exhibit 34, vary from 0.08 to 0.95. The distribution of probabilities is as follows:

Probability of Survival	No. of Route Segments
0-9%	1
10-19	2
20-29	1
30-39	2
40-49	6
50-59	2
60-69	6
70-79	6
80-89	3
90-99	5
	34

There are just a few route segments with low probability of survival intact. These route segments have large numbers of bridges both under and over the railroad. Although each bridge has only a small likelihood of damage, when there are many bridges the likelihood is high that at least one will be sufficiently damaged to deny use of the route segment. Those route segments with high probabilities of survival typically have just a handful of bridges. Many of these segments are short.

Using the criterion of less than 50 percent survival probability to exclude a route segment from post-earthquake use, the bridge analysis would eliminate twelve railroad route segments. Six of these are major intercity lines; the other six are branch lines. Several of the branch lines, however, are very important. For example, the UP's Los Angeles to Long Beach route segment provides the only railroad access to Terminal Island which houses important port facilities. Other branch lines provide useful access to industry but are less critical to survival and recovery.

EXHIBIT 34

PROBABILITY THAT BRIDGES ON RAILROAD ROUTE SEGMENTS WOULD SURVIVE A 7.5 MAGNITUDE EARTHQUAKE ON THE NEWPORT-INGLEWOOD FAULT

RR	From	To	Support Bridges	Spans Under	Spans Over	Probability	Out
ATSF	San Bernardino	Los Angeles	17	38	19	0.08	X
ATSF	Fullerton	Los Angeles	14	25	27	0.12	X
ATSF	Atwood	Orange	2	6	0	0.74	
ATSF	Atwood	Fullerton	3	3	3	0.78	
ATSF	Los Angeles	El Segundo	3	5	28	0.33	X
ATSF	El Segundo	Long Beach	4	8	13	0.45	X
ATSF	Fullerton	Orange	3	7	5	0.60	
SP	Saugus	Burbank	4	11	14	0.37	X
SP	Oxnard	Burbank	2	8	11	0.47	X
SP	Burbank	Los Angeles	3	7	11	0.49	X
SP	El Monte	Los Angeles	4	6	18	0.42	X
SP	Vernon	Whittier	4	8	4	0.59	
SP	Los Angeles	Culver City	2	3	3	0.78	
SP	Culver City	Santa Monica	1	1	11	0.68	
SP	Santa Monica	Venice	3	3	0	0.86	
SP	Los Angeles	Vernon	4	5	8	0.61	
SP	Vernon	Firestone Park	3	6	0	0.74	
SP	Firestone Park	W. Anaheim	5	7	11	0.49	X
SP	Firestone Park	Watts	1	1	0	0.95	
SP	Watts	El Segunto	2	3	9	0.65	
SP	Watts	Torrance	3	5	4	0.69	
SP	Watts	Compton	1	1	0	0.95	
SP	Watts	Lynwood	2	2	0	0.90	
SP	Firestone Park	Lynwood	1	1	0	0.95	
SP	Lynwood	Compton	3	3	0	0.86	
SP	Lynwood	Stanton	4	8	9	0.50	
SP	Compton	San Pedro	2	4	10	0.60	
SP	Compton	E. Long Beach	3	8	13	0.45	X
SP	Stanton	W. Anaheim	2	2	0	0.90	
SP	N. Anaheim	Anaheim	3	4	0	0.81	
UP	Whittier Jc.	Fullerton	1	3	4	0.76	
UP	City of Industry	Whittier Jc.	2	3	5	0.74	
UP	Whittier Jc.	Los Angeles	8	11	23	0.28	X
UP	Los Angeles	Long Beach	11	26	18	0.15	X

Ground Failure

Seven railroad route segments cross the Newport-Inglewood fault where surface rupture can be expected in a 7.5 magnitude earthquake. The track near the fault is likely to be twisted and distorted in grotesque ways that render it completely unusable until replaced. Railroad grading is likely to be ruptured and displaced at the fault and subjected to upheaval and differential settling in adjacent areas where earthquake intensity is high. This violent damage is likely to deny port-earthquake use of the following seven route segments:

Railroad	Route Segment From	Route Segment To	Denied Due to Bridge Failure
ATSF	Los Angeles	El Segundo	Yes
SP	Los Angeles	Culver City	No
SP	Watts	El Segundo	No
SP	Watts	Torrance	No
SP	Compton	San Pedro	No
SP	Compton	E. Long Beach	Yes
UP	Los Angeles	Long Beach	Yes

The SP route segment between Compton and East Long Beach is particularly vulnerable because it lies on or very near the fault for several miles.

Railroad lines subjected to earthquake intensities of R-F VIII or less are not particularly susceptable to ground failure. Railroad grades are old and natural settlement is complete. Nonetheless, a number of railroad lines were constructed on alluvial soil that is subject to both liquifaction and differential settlement. Soil data are not available that would support reliable estimates of areas that are most vulnerable to ground failure. However, a careful examination of geological maps suggests that ground failure may occur at some point on each of the following 24 route segments:

Railroad	Route Segment From	Route Segment To	Denied due to Bridge Failure?
ATSF	Orange	San Diego	No
ATSF	Fullerton	Los Angeles	Yes
ATSF	El Segundo	Long Beach	Yes
ATSF	San Bernardino	Los Angeles	Yes

SP	El Monte	Los Angeles	Yes
SP	Culver City	Santa Monica	No
SP	Santa Monica	Venice	No
SP	Los Angeles	Vernon	No
SP	Vernon	Whittier	No
SP	Vernon	Firestone Park	No
SP	Firestone Park	W. Anaheim	Yes
SP	Firestone Park	Watts	No
SP	Watts	Compton	No
SP	Watts	Lynwood	No
SP	Firestone Park	Lynwood	No
SP	Lynwood	Compton	No
SP	Lynwood	Stanton	No
SP	Stanton	W. Anaheim	No
SP	W. Anaheim	Anaheim	No
SP	Burbank	Los Angeles	Yes
SP	Burbank	Oxnard	Yes
SP	Burbank	Saugus	Yes
UP	Pomona	City of Industry	No
UP	Whittier Jc.	Los Angeles	Yes

Twenty-two of the twenty-four route segments contain bridges subject to earthquake damage. Use of nine of these segments is expected to be denied because of bridge failure. In these instances ground failure would complicate restoration of the lines. For the 13 route segments with probabilities of bridge survival greater than 0.5, ground failure is a complicating factor that in combination with the risk of bridge failure suffices to eliminate the route segment from post-earthquake planning.

Bridges on two route segments--Orange to San Diego (ATSF) and Pomona to City of Industry (UP)--do not have threatened bridges but may be subject to ground failure. The Orange to San Diego line parallels the fault near its southern end and lies less than ten km east of the fault. There are some cuts that might slide where this line passes through the low hills northeast of San Clemente. Further south, the line is close to the coast where failure of bluffs could cause serious damage. Because of its location, it seems unreasonable to expect this line to survive intact. The UP line between Pomona and the City of Industry is built on alluvial soil that follows San Jose Creek and the San Gabriel River for several miles. Ground failure at some point along this route seems likely.

The Surviving Railroad Network

Despite the fact that 31 of 59 railroad route segments would be unavailable for service after a major earthquake on the Newport-Inglewood fault, the surviving network would be reasonably well connected and could support large volumes of intercity traffic. As illustrated in Exhibit 35, major railroad routes from the north, northeast and east are likely to remain intact. Thus traffic between the east and Northern California via the ATSF and SP lines need not be affected. The SP connection between Colton and Palmdale lies closest to the earthquake damage zone but is expected to survive.

The SP's coast route would be unaffected as far south as Oxnard; however, the main line between Oxnard and Burbank is expected to suffer both bridge damage and ground failure. There is an alternative route via the Santa Clara valley that connects Oxnard with Saugus. This line is inactive today, used principally for car storage, but it is in satisfactory condition and could be brought into service if needed. This route is included in Exhibit 35.

The ATSF route between Orange and San Diego would be closed by ground failure near San Clemente. This damage would isolate San Diego from the east unless service were available via the San Diego & Arizona Eastern and the Tijuana & Tecate--an unlikely prospect at present. Railroad service to the Los Angeles area would be severely impaired. Access from the north via Saugus would be denied by bridge damage and ground failure. Routes from the east via San Bernardino would be usable as far as El Monte, Pomona and Fullerton. Service beyond these points would require intermodal transfers to motor carriers and highway carriage over emergency routes.

Post-Earthquake Railroad Capacity

Post-earthquake intercity railroad capacity would approach present capacity outside the Los Angeles Basin. Large volumes of supplies and materials could be brought to railroad yards in the San Bernardino-Colton area. Adequate yard capacity is available in

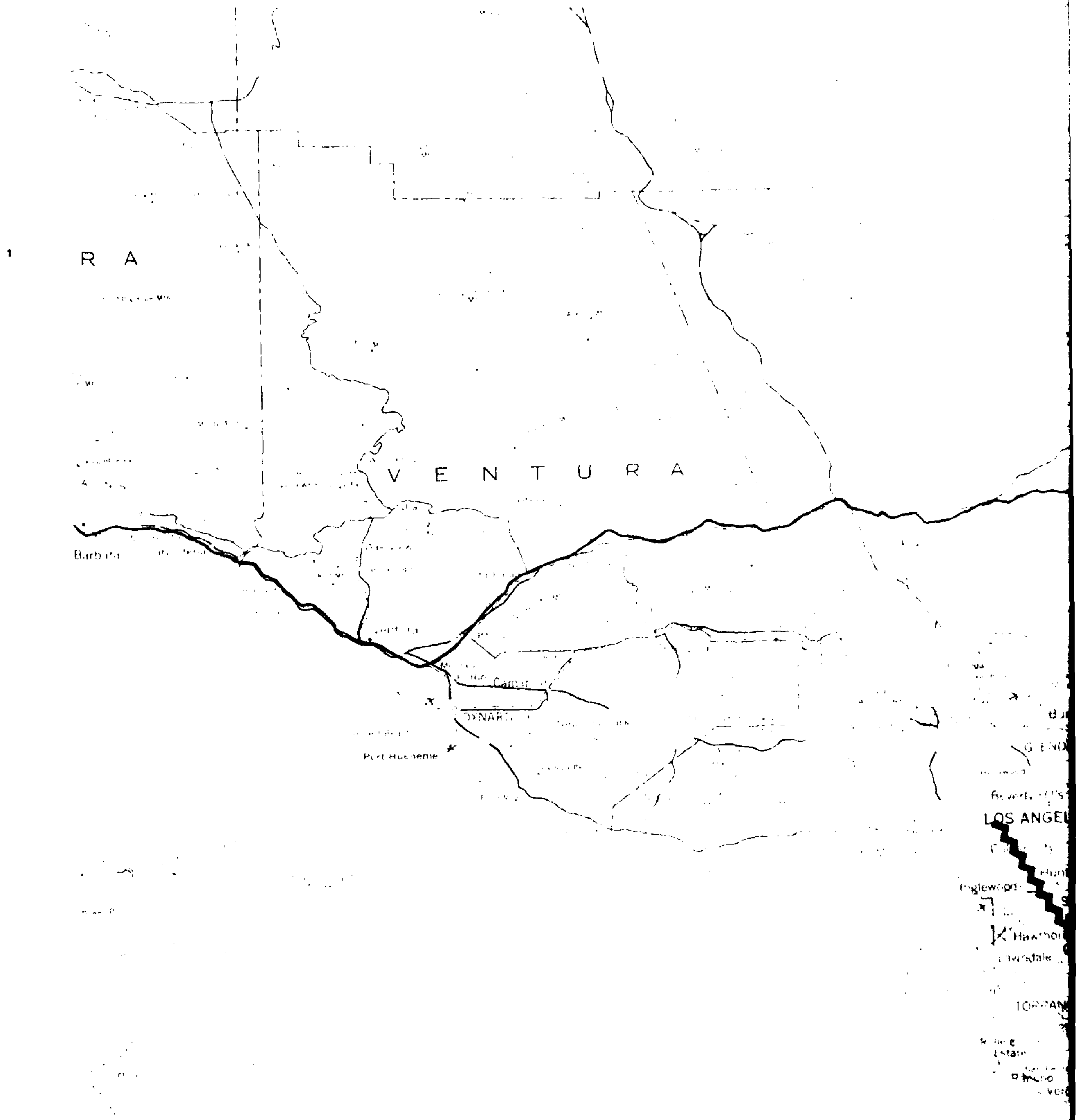


Exhibit 35

RAILROAD NETWORK SURVIVING NEWPORT-INGLEWOOD FAULT EARTHQUAKE

Key:

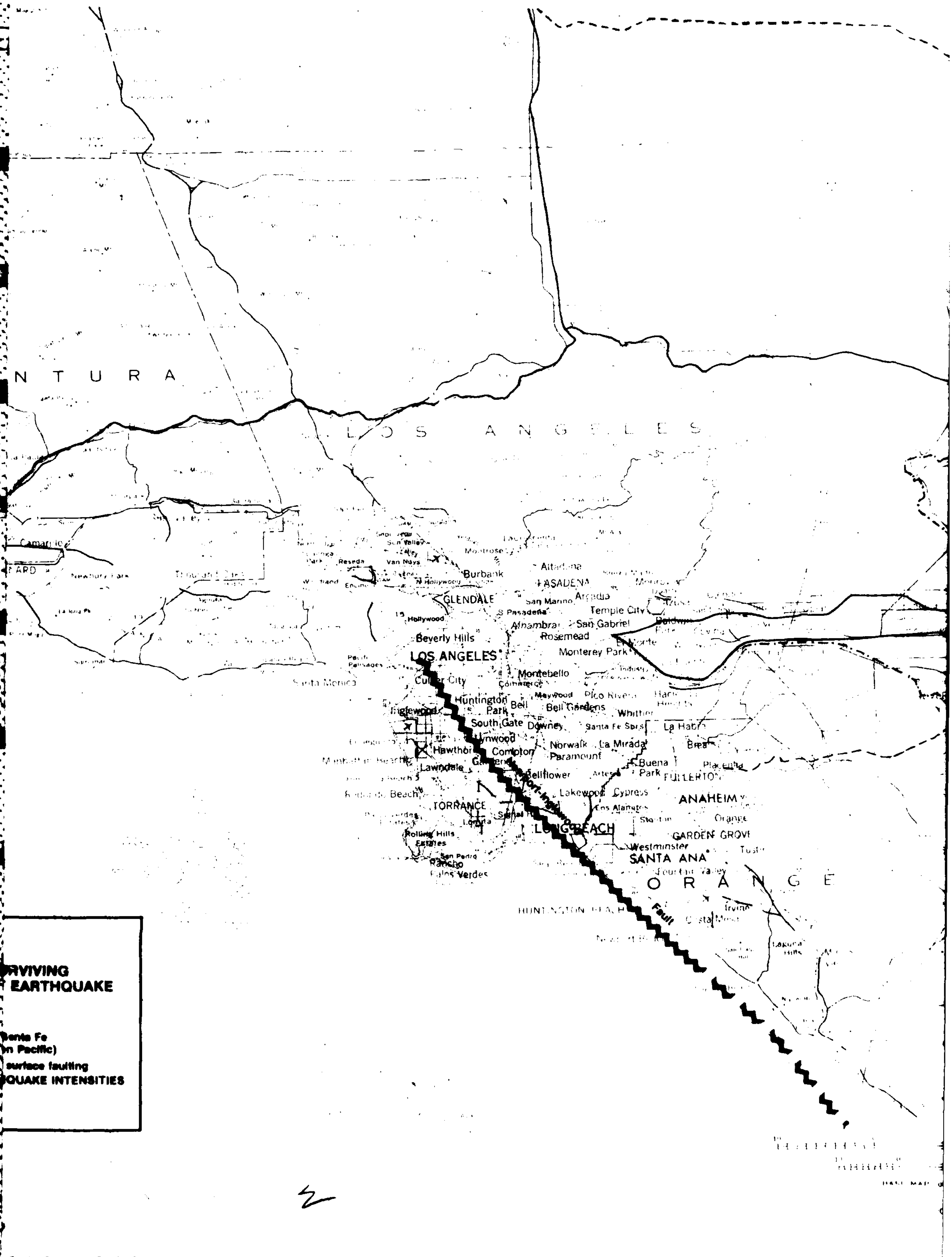
— Southern Pacific
--- Atchison, Topeka & Santa Fe
-·- Western Pacific (Union Pacific)
Fault line indicated estimated extent of surface faulting

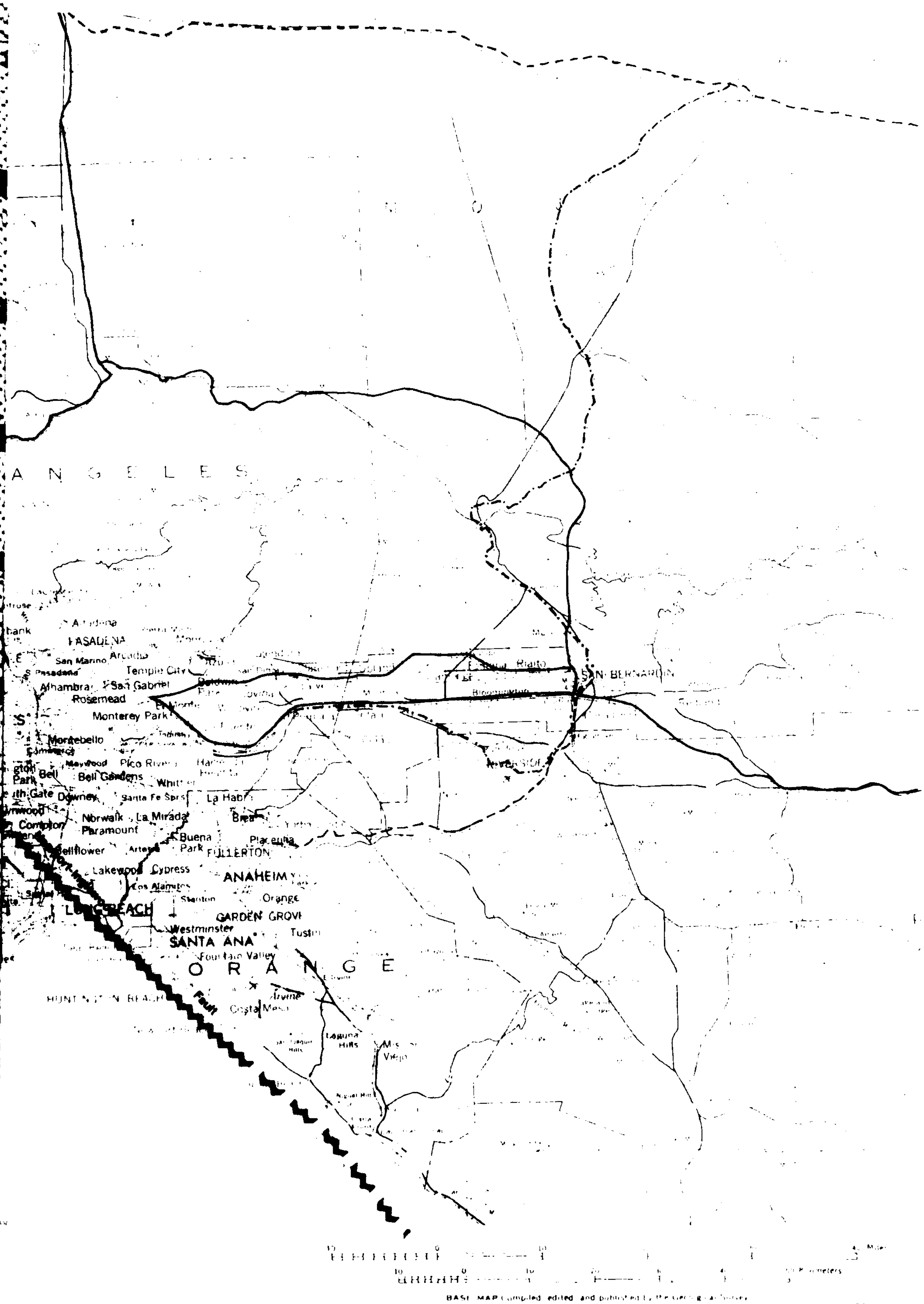
ESTIMATED MODIFIED MERCALLI EARTHQUAKE INTENSITIES

VIII
VII

1

2


N T U R A
L O S A N G E L E S
O R A N G E
Camarillo
Newbury Park
Reseda
Van Nuys
Sun Valley
Encino
N Hollywood
Montrose
Burbank
GLENDALE
Altadena
PASADENA
San Marino
Arcadia
S Pasadena
Temple City
Alhambra
San Gabriel
Rosemead
Hollywood
Beverly Hills
LOS ANGELES
Monterey Park
Santa Monica
Culver City
Montebello
Commerce
Huntington Park
Bell
Maywood
Bell Gardens
Pico Rivera
Whittier
Inglewood
South Gate
Downey
Santa Fe Sprs
La Habra
Lynwood
Norwalk
La Mirada
Brea
Hawthorne
Compton
Paramount
Buena Park
FULLERTON
Lawndale
Bellflower
Lakewood
Cypress
ANAHEIM
Redondo Beach
TORRANCE
Los Alamitos
Orange
Rolling Hills Estates
LONG BEACH
GARDEN GROVE
Westminster
SANTA ANA
San Pedro
Rancho Palos Verdes
Fountain Valley
HUNTINGTON BEACH
Irvine
Costa Mesa
Newport-Inglewood Fault
RVIVING
EARTHQUAKE
Santa Fe
n Pacific)
surface faulting
QUAKE INTENSITIES


A N G E L E S
SAN BERNARDINO
Rialto
Bloomington
Riverside
PASADENA
San Marino
Arcadia
S Pasadena
Temple City
Alhambra
San Gabriel
Rosemead
El Monte
Monterey Park
Montebello
Commerce
Maywood
Pico Rivera
Bell
Bell Gardens
Whittier
Downey
Santa Fe Sprs
La Habra
Norwalk
La Mirada
Brea
Compton
Paramount
Buena Park
Placentia
Bellflower
Artesia
FULLERTON
Lakewood
Cypress
ANAHEIM
Los Alamitos
Stanton
Orange
LONG BEACH
GARDEN GROVE
Westminster
Tustin
SANTA ANA
Fountain Valley
O R A N G E
Irvine
Costa Mesa
Laguna Hills
Mission Viejo
Fault
BASE MAP Compiled, edited and published by the Geological Survey

that area to handle substantial volumes of traffic. Of the five rail lines that extend west from San Bernardino-Colton, four are likely to survive but each of these would be severely truncated. The SP could handle a small amount of traffic using sidings and industrial tracks in the City of Industry area. The UP yards in Montebello are not likely to be accessable; only limited switching would be available elsewhere. The ATSF is also short of switching capability west of San Bernardino.

Efficient post-earthquake transportation would require a scheme in which all switching and terminal activities were performed in the San Bernardino-Colton area. From there, trains could be dispatched to set out loads and pick up empties from specific sidings nearer to the earthquake casualties. Strict car control would be needed to keep the sidings clear and to avoid congestion.

Post-earthquake railroad repairs should be coordinated with highway repairs for maximum coverage. Early attention might best focus on building emergency TOFC ramps on the surviving lines near El Monte, Pomona and Atwood. These could be used for transshipment to motor carriers and delivery over emergency roads. Priority railroad repair needs include extending rail lines toward Long Beach and into the San Fernando Valley. It would also be helpful to open the ATSF line to San Diego beginning from Atwood.

PIPELINE TRANSPORTATION

The major intercity natural gas pipeline networks serving Southern California are not likely to be damaged by a 7.5 magnitude earthquake on the Newport-Inglewood fault. Nonetheless the distribution system in the Los Angeles basin is vulnerable to considerable damage as are large lines to a number of electric power stations located on or near the coast.

Petroleum and petroleum product pipelines would be vulnerable to considerable damage. All of the refineries in the Los Angeles area are close to the coast where they are vulnerable to earthquake

damage. Petroleum gathering lines from Southern California oil fields are exposed to severe damage, as are product lines originating at damaged refineries.

Natural Gas Pipelines

Natural gas pipelines entering Southern California from the east and northeast are not likely to be disturbed by an earthquake on the Newport-Inglewood fault. However, the two Pacific Lighting Service lines from the Central Valley via Soledad Canyon and Tejon Pass might be damaged at junctions in the San Fernando Valley near Reseda. High intensities and poor soil in this area are likely to cause some damage, though some residual capacity is likely.

Major pipeline connections located in the San Bernardino Corridor are likely to survive as are connections to underground storage at Montebello and East Whittier. Access to underground storage at Playa del Rey may be denied by a pipeline rupture at the fault near Culver City. Distribution systems may survive as far west as Pasadena and El Monte. Brakes should be expected southwest of this line because of the earthquake intensity (R-F VIII or greater).

Gas service to major coastal power plants is likely to be disrupted. The Scattergood, El Segundo, Redondo Beach, Harbor, Long Beach, Alamitas, Haynes and Huntington Beach power plants are all located within a few km of the fault. Damage to these plants may be extensive. Pipelines supplying natural gas to these plants cross the fault breaks where they are subject to potential rupture. Power plants in the San Bernardino area, Pasadena, Glendale, Burbank and Oxnard are likely to survive as are their natural gas supply lines. These surviving plants have less capacity than the coastal plants. As a result, electricity on a reduced scale would be available to serve undamaged areas.

Emergency repairs should focus on restoring natural gas to the San Fernando Valley. Reestablishing electric service should have a high priority, but natural gas supply may not be critical to this

task. The desirability of reestablishing service to power plants would depend on the damage to the plants and the availability of alternative fuels. The massive task of repairing distribution lines needs to be undertaken when crews and equipment are available. This effort is likely to take many months. There is no promise of early breakthroughs.

Petroleum and Petroleum Product Pipelines

All of the oil refineries in the Los Angeles area are subject to earthquake damage. The largest of these--Chevron, Mobil, Shell, Union, Atlantic Richfield and Texaco--are located close to the region of surface faulting. These refineries are served by crude pipelines from California oil fields and by pipelines from marine terminals at San Pedro and Terminal Island. Supply pipelines are likely to rupture at the refineries or at the port or both.

Product pipelines are likely to be ruptured near refineries or where they cross the fault. Repairs to these pipelines are not likely to take as long as repairs to the refineries that serve them.

AIRPORTS

In sharp contrast to the south San Andreas fault earthquake, a major earthquake on the Newport-Inglewood fault is likely to cause extensive damage to major airports in the Los Angeles area. The Los Angeles International, Long Beach and Orange County airports and the El Toro Marine Air Station are all located within 10 km of the fault. These airports are likely to sustain runway damage--sufficient to keep them out of service for a considerable period. The Burbank and Van Nuys Airports are located about 17 km from the expected end of the surface faulting in an area where extensive highway and railroad bridge damage is expected. It seems likely that there would be some damage to runways and aprons at the Burbank Airport in addition to extensive damage to structures. However, the airport may be available for limited use by military transport

aircraft, particularly C130s. Support to the San Fernando Valley is also available from the Ventura County Airport at Oxnard, which is not likely to be damaged.

To the east, airports can be expected to survive largely intact. The Ontario International Airport, Riverside Airport, Norton and March Airforce Bases should be available to handle large volumes of emergency supplies and to evacuate survivors. Unfortunately, these available airports could be linked to damaged areas only by the damaged highway and railroad networks. Some critical support could be provided by helicopters operating to cleared areas and light aircraft using emergency fields, but the volume would be small.

Loss of the Los Angeles International Airport would be the largest single blow to air transport capability. In all the damaged airports represent about two thirds of the region's air lift capability.

The principal priority in rebuilding should be opening one airport or one runway in the Los Angeles-Long Beach area. This would provide more direct support to earthquake casualties. Limited capability in Burbank-Van Nuys area is also important to supply the San Fernando Valley.

WATERWAYS AND PORT FACILITIES

A major earthquake on the Newport-Inglewood fault is likely to cause extensive damage to the ports of Los Angeles and Long Beach. Elsewhere, port facilities in San Diego and Port Hueneme are likely to survive without damage.

The ports of Los Angeles and Long Beach are located next to one another on San Pedro Bay, inside a large artificial breakwater. Port facilities extend from San Pedro to Seal Beach. Major activity occurs on Terminal Island which is connected to the mainland by three highway and one railroad bridge. There are many channels and

basins, docks, container terminals and other port facilities. Collectively, the ports are the largest on the U.S. west coast.

The Newport-Inglewood fault passes very close to the ports. At San Pedro, on the west, the fault is about 4 km from the nearest port facilities. At Seal Beach, on the east, the fault is within 2 km of the coast. A large part of the port facilities are likely to be subjected to earthquake intensities of R-F IX or greater. No facilities are likely to experience intensities less than R-F VIII.

The ground under the ports is not particularly stable. An oval of land 1.5 km north of Terminal Island has been subject to extensive subsidence attributed to the removal of petroleum. The affected area covers about 40 sq. km and includes most of the port area. A program of water repressurization has halted the subsidence. Nevertheless, the soil remains unstable and the effects of a major earthquake can only be hypothesized.

A major earthquake on the Newport-Inglewood fault is likely to cause sufficient damage to close both Los Angeles and Long Beach ports for a considerable period of time. Although pile supported piers may survive, quay walls are likely to fail because of liquifaction of the filled land behind them. Port cranes and container cranes are likely to be thrown off their tracks or toppled by intense shaking. Crane rails are likely to be twisted as ground fails. Underground utilities and petroleum and water pipelines are likely to be broken by differential settlement. The harbor channels are dredged to 14 meters in soil that has been subject to subsidence. It would not be surprising if channel sides slipped under intense shaking, blocking all or part of the harbor from deep draft ships.

The ports would be isolated from the surrounding territory. The UP lift bridge to Terminal Island would, as a minimum, be misaligned so that it could not be used. At least one of the three highway bridges is likely to be damaged beyond use. The collapse of the Thomas or Desmod bridges would isolate sections. Even so highway route segments serving the port are expected to be ruptured at the fault.

Repairs to the ports are likely to be long and costly. They probably should not be undertaken at once, relying, rather, on surface modes to bring ocean freight to the damaged area. The ports of San Diego and Port Hueneme could handle emergency supplies and some materials for reconstruction. As surface connections are available to the ports of Los Angeles and Long Beach, repair materials could be brought overland and repairs could commence, beginning with the bridges to Terminal Island.

DAMAGE OVERVIEW

A major earthquake on the Newport-Inglewood fault would cause extensive damage in Los Angeles, Long Beach and northwestern Orange County. Because of limited surface faulting, the damage would be highly localized. However, because of the strategic location of the fault, heavy damage is likely to be inflicted on major airports and on major port facilities. In sharp contrast, damage to highways, railways and natural gas pipelines would be restricted to local service to damaged areas. Intercity routes would remain intact, with some detours necessary. Highways would be most seriously affected with through routes on I5 and U.S. 101 disrupted. Nonetheless, one third of the pre-earthquake intercity highway capacity would remain.

Emergency transportation services to earthquake victims would need to exploit modal combinations. Only highway emergency routes could be expected to reach most victims. These would use surface streets, avoiding areas of heavy debris and fallen bridges. The highway distribution routes could be served by highway, railway, air or maritime carriers. Survivors in the Los Angeles-Santa Monica-Long Beach area could be supplied by distribution trucks that secure freight from intercity motor carriers and railheads in the Pomona-Fullerton area. Air service would be available at Ontario or the Air Force Base near San Bernardino. Ocean service could come from San Diego via highway. Survivors in the San Fernando

Valley would be supplied by distribution trucks that secure freight from intercity motor carriers and railroads in the Oxnard area. Limited air service would be available at Ventura County airport and marine service would be available at Port Hueneme.

Natural gas trunk pipelines would survive intact. However, distribution to the damaged area would be interrupted by breaks in feeder lines. Gas sources to coastal power plants would be interrupted by pipeline breaks at or near the fault.

The survival of petroleum pipelines and product pipelines would be of little immediate consequence because of damage to the major refineries and the ports of Los Angeles and Long Beach. Nonetheless petroleum pipeline breaks could pose fire hazards that would be of great concern.

In the aggregate supplying earthquake survivors and providing materials for rebuilding would depend on the adequacy of emergency highways in the damaged area. Adequate intercity routes would survive to provide for all critical needs.

VIII. RESEARCH APPRAISAL

The research described in this report used available information to make a preliminary assessment of the damage that each of four earthquakes might have on transportation in California. The results give an indication of the damage that might result from any of four major earthquakes. However, the results should not be viewed as conclusive for the following reasons:

- There is small likelihood that any of the example earthquakes will occur as described. Historically, similar magnitude earthquakes on the same fault have exhibited wide variations in earthquake effects.
- Estimates of earthquake intensities are inexact because of deficiencies in soil data and because of inaccuracies in estimating ground accelerations and attenuations.
- Estimates of the effects that ground accelerations, with their different frequency spectra, would have on given structures require complex structural calculations that have not been made.

Nonetheless, information has been generated that can have considerable value in mitigating the effects of a major earthquake. Although inexact, estimated earthquake intensities do give an indication of what might be expected in the event of a major earthquake. These intensities can be used as guidelines when deciding what activities are justified to reduce the destruction from a major earthquake and when preparing contingency plans to respond to an earthquake disaster.

The results of the research provide a basis for focusing attention on past earthquake transportation and on the problems

Furthermore, the railroad bridge data are much less specific and complete than the highway bridge data. An effort to provide consistency and completeness to the railroad data would be most welcome. Soil data for railroad bridges are also unavailable.

A fruitful direction for further research would be selective soil borings for designated critical facilities. It is possible to identify a relatively small number of key facilities for which good soil data would be most helpful. These include:

- Key airports, e.g., LAX, SFO;
- Key bridges, e.g., Golden Gate, San Francisco-Oakland Bay, Terminal Island, other San Francisco Bay crossings, Carquinez Strait, and Martinez railroad bridges;
- Key compressor/pumping stations; and
- Key port facilities.

These data could be used to make better assessments of potential damage to these key facilities.

Better structural information would also be useful for key structures, like the southern Golden Gate Bridge approach, elevated freeway structures, and high bridges over key interchanges. These data could support better damage assessments of these structures.

Another direction for additional work would be an investigation of local problems. This investigation could include studies of access, debris clearance, detour selection, construction priorities and other problems of a critical nature. It has been argued that these are local problems that should be sponsored by local governments. However, local groups are not often equipped to undertake earthquake analyses. A research task directed toward procedures for conducting local research could be most helpful. Using three or four areas as examples, and recognizing the diversity of earthquake damage patterns, a useful guide to local earthquake planning could be prepared.

that can be expected with intercity transportation. The research has accommodated the study's underlying assumption by avoiding the temptation to predict how individual structures might be affected by a specific earthquake example.

Highways and railways were combined into route segments, each containing multiple structures that could be treated collectively. The likelihood of damage to one of a set of similar structures subjected to similar accelerations is much greater than the likelihood of damage to any given structure. Thus one can accept the post earthquake denial of a route segment, while the extent of damage to a particular structure is uncertain.

Ports and airports presented greater difficulties because for any earthquake there are few of them in the areas of intense damage. However, damage to both types of facilities is most likely to come from soil failure. Therefore, good soil information yields better indications of potential damage than do more accurate estimates of earthquake intensity.

The accuracy of the earthquake damage assessments can be improved by improving the descriptive data concerning structures and the data on soil that supports them. Descriptions of the highway bridges in the sample follow a uniform state code. Spot checks revealed that, with few exceptions these descriptions are both accurate and consistent. Little would be gained by seeking additional information. However, detailed structural investigations have not been made for very many bridge types. The paucity of data on old bridges is particularly severe. Furthermore, there are very few data on soil under bridge abutments or piers. Although structural and soil information would be difficult and costly to collect, they would be most helpful.

The descriptions of railroad bridges are not consistent. Each railroad has its own code. Although the codes are similar there are some important differences in the descriptive information.

A major step toward identifying gross earthquake impacts has been completed. The research results should be useful in improving estimates of transportation impacts for other earthquakes. Nonetheless, it is time to consider the detailed needs of earthquake survivors and the manner in which these needs can be met.

APPENDIX

EARTHQUAKE INTENSITY AND MAGNITUDE SCALES

Rossi-Forel Scale,
Modified Mercalli Scale,
and Richter Scale

EARTHQUAKE INTENSITY

Earthquake intensity is a measure of an earthquake's effects in a given locality. For historical earthquakes, it is based on actual observations of earthquake effects at specific places. Because the data used for assigning intensities can be obtained only from direct firsthand reports, considerable time-- weeks or months-- is sometimes needed before an intensity map can be assembled for a particular earthquake. Earthquake intensity depends generally on earthquake type, distance from epicenter and the condition of the soil at the point of observation. The Rossi-Forel scale has values from I to X; the Modified Mercalli intensity scale has values ranging from I to XII.

ROSSI-FOREL INTENSITY SCALE

The first scale to reflect earthquake intensities was developed in the 1880s by de Rossi of Italy and Forel of Switzerland. This scale, with values from 1 to 10, was used for about two decades. The most commonly used form of the Rossi-Forel (R-F) scale is:

I Microseismic shock. Recorded by a single seismograph or by seismographs of the same model, but not by several seismographs of different kinds: the shock felt by an experienced observer.

II Extremely feeble shock. Recorded by several seismographs of different kinds; felt by a small number of persons at rest.

III Very feeble shock. Felt by several persons at rest; strong enough for the direction or duration to be appreciable.

IV Feeble shock. Felt by persons in motion; disturbance of movable objects, doors, windows, cracking of ceilings.

V Shock of moderate intensity. Felt generally by everyone; disturbance of furniture, beds, etc., ringing of some bells.

VI Fairly strong shock. General awakening of those asleep; general ringing of bells; oscillation of chandeliers; stopping of clocks; visible agitation of trees and shrubs; some startled persons leaving their dwellings.

VII Strong shock. Overthrow of movable objects; fall of plaster; ringing of chuch bells; general panic, without damage to buildings.

VIII Very strong shock. Fall of chimneys; cracks in the walls of buildings.

IX Extremely strong shock. Partial or total destruction of some buildings.

X Shock of extreme intensity. Great disaster; ruins; disturbance of the strata, fissures in the ground, rock falls from mountains.

MODIFIED MERCALLI INTENSITY SCALE

A need for a more refined scale increased with the advancement of the science of seismology, and in 1902 the Italian seismologist, Mercalli, devised a new scale on a I to XII range. The Mercalli scale was modified in 1931 by American seismologists Harry O. Wood and Frank Neumann to take into account modern structural features. The Modified Mercalli (MM) scale reads as follows:

I Not felt except by a very few under especially favorable circumstances.

II Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.

III Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration like passing of truck. Duration estimated.

IV During the day felt indoors by many, outdoors by few. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking buildings. Standing motor cars rocked noticeably.

V	Felt by nearly everyone, many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbances of trees, poles and other tall objects sometimes noticed. Pendulum clocks may stop.
VI	Felt by all, many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight.
VII	Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motor cars.
VIII	Damage slight in specially designed structures; considerable in ordinary substantial buildings, with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving motor cars disturbed.
IX	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.
X	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks.
XI	Few, if any, (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.
XII	Damage total. Practically all works of construction are damaged greatly or destroyed. Waves seen on ground surface. Lines of sight and level are distorted. Objects are thrown upward into the air.

RICHTER MAGNITUDE SCALE

The Richter magnitude scale, named after Dr. Charles F. Richter, Professor Emeritus of the California Institute of Technology, is the scale most commonly used to express the energy released during an earthquake. On this scale, the earthquake's magnitude is expressed in whole numbers and decimals. The magnitude varies logarithmically with the wave amplitude of the earthquake recorded by the seismograph. Each whole number step of magnitude on the scale represents an increase of 10 times in the measured wave amplitude of an earthquake. Thus, the amplitude of an 8.3 magnitude earthquake is not twice as large as a shock of magnitude 4.3, but 10,000 times as large. For every unit increase in magnitude, there is a 31-fold increase in energy released. Thus, a magnitude 8.3 earthquake releases almost one million times more energy than one of magnitude 4.3.

An earthquake of magnitude 2 on the Richter scale is the smallest earthquake normally felt by humans. Earthquakes with a Richter magnitude of 7 or more are commonly considered to be major. The Richter magnitude scale has no fixed maximum or minimum; observations have placed the largest recorded earthquakes in the world at about 8.9, and the smallest at -3. Earthquakes with magnitudes smaller than 2 are called "microearthquakes".

Richter magnitudes are not used to estimate damage.

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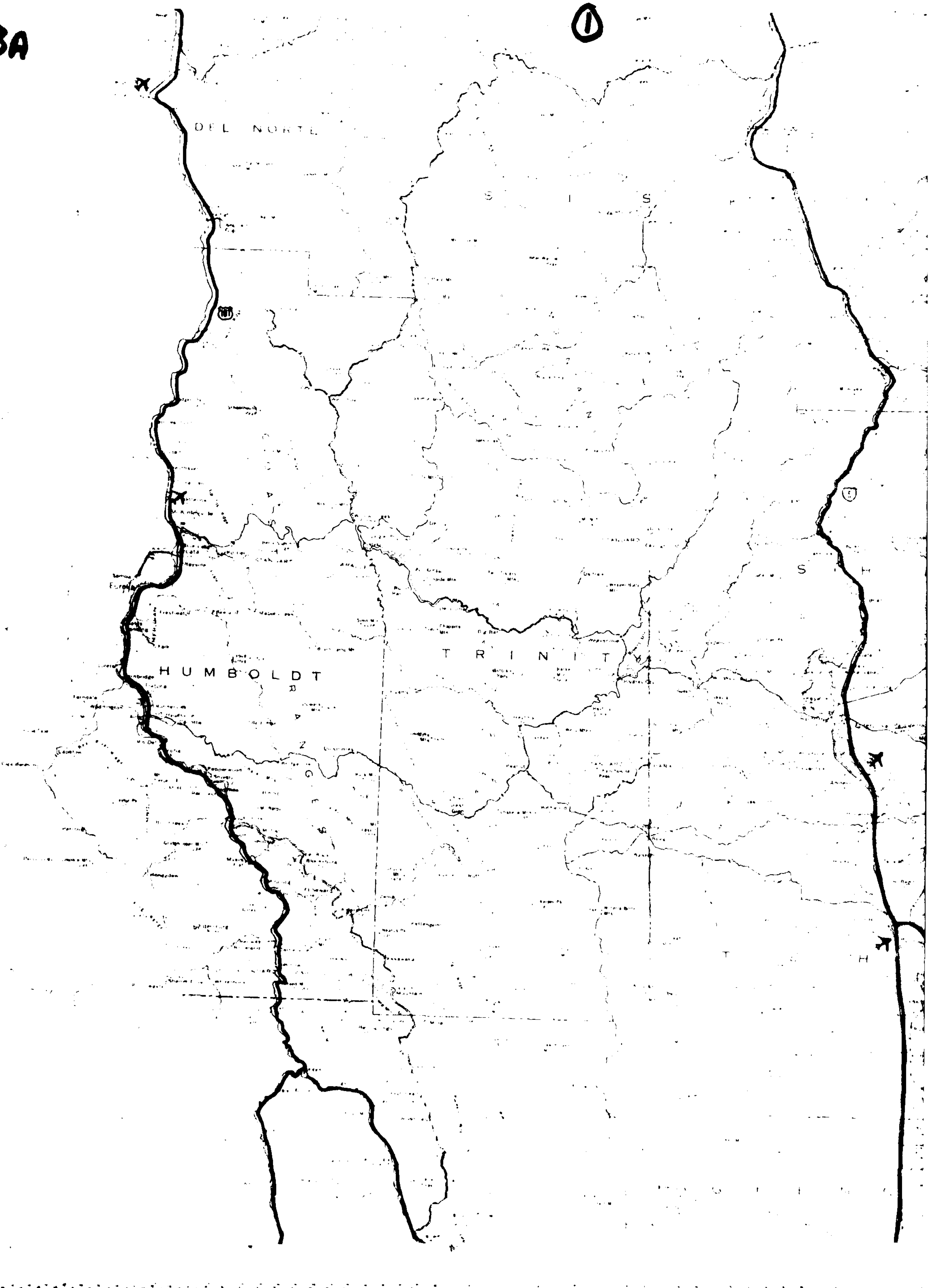

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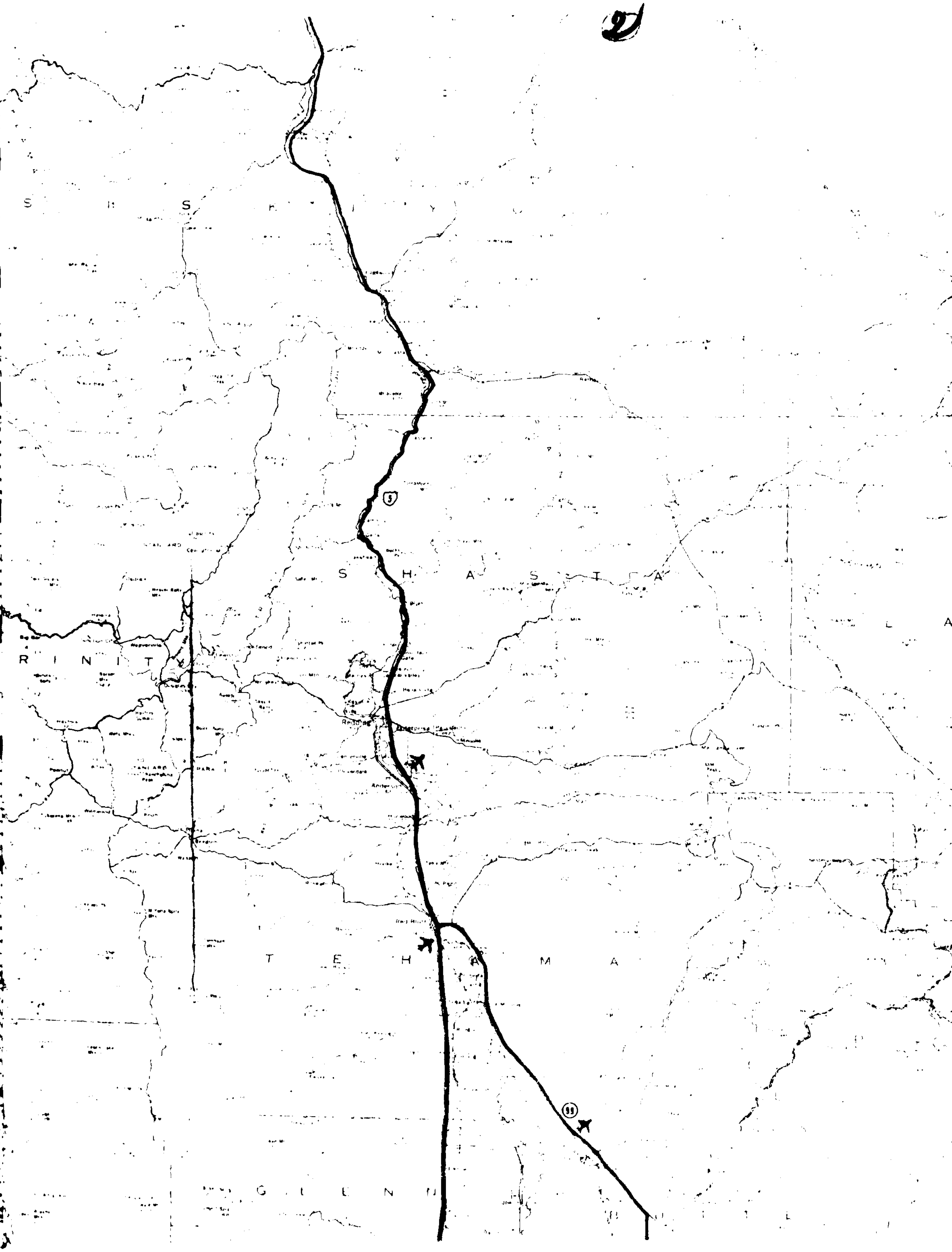

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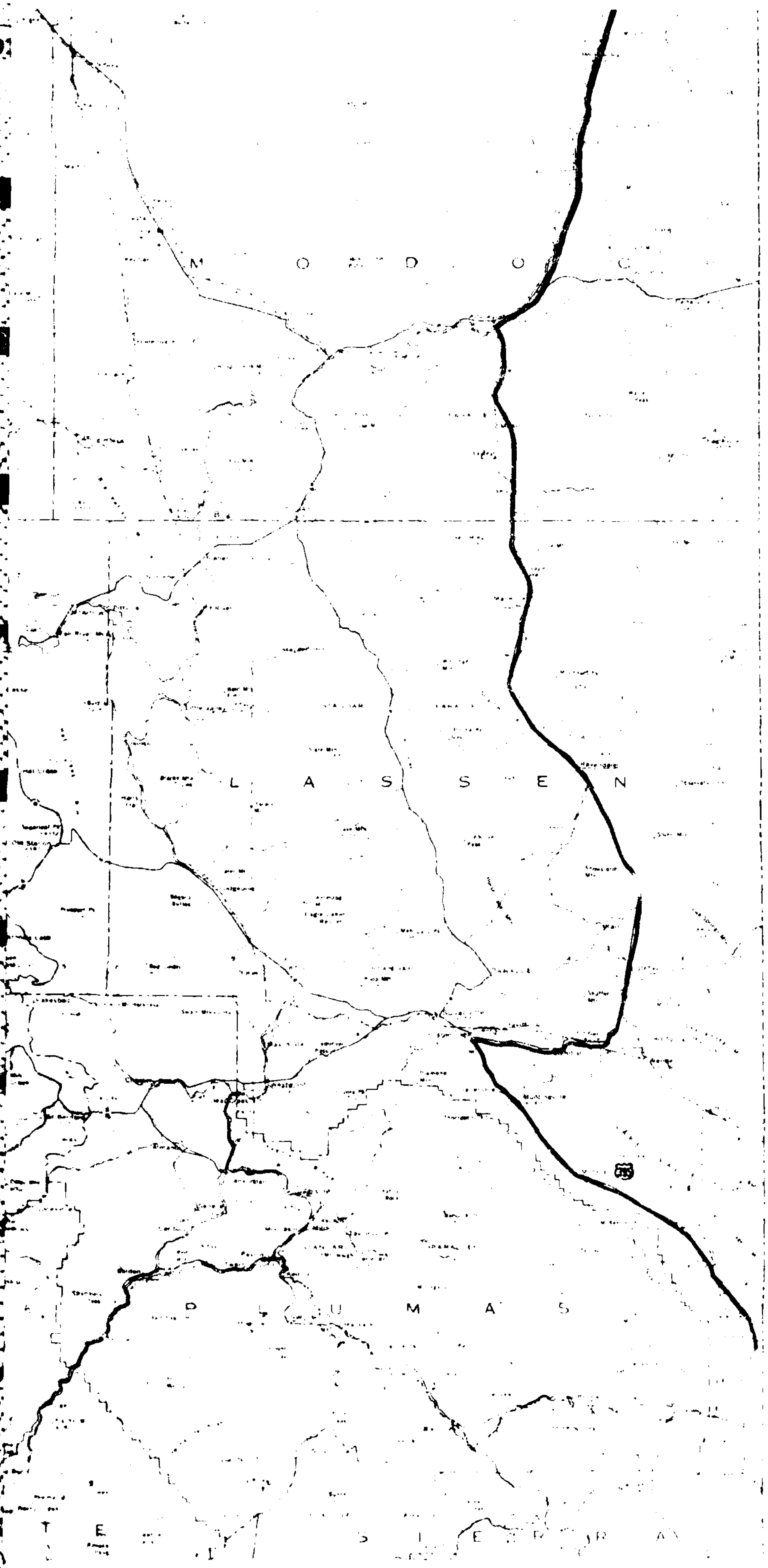

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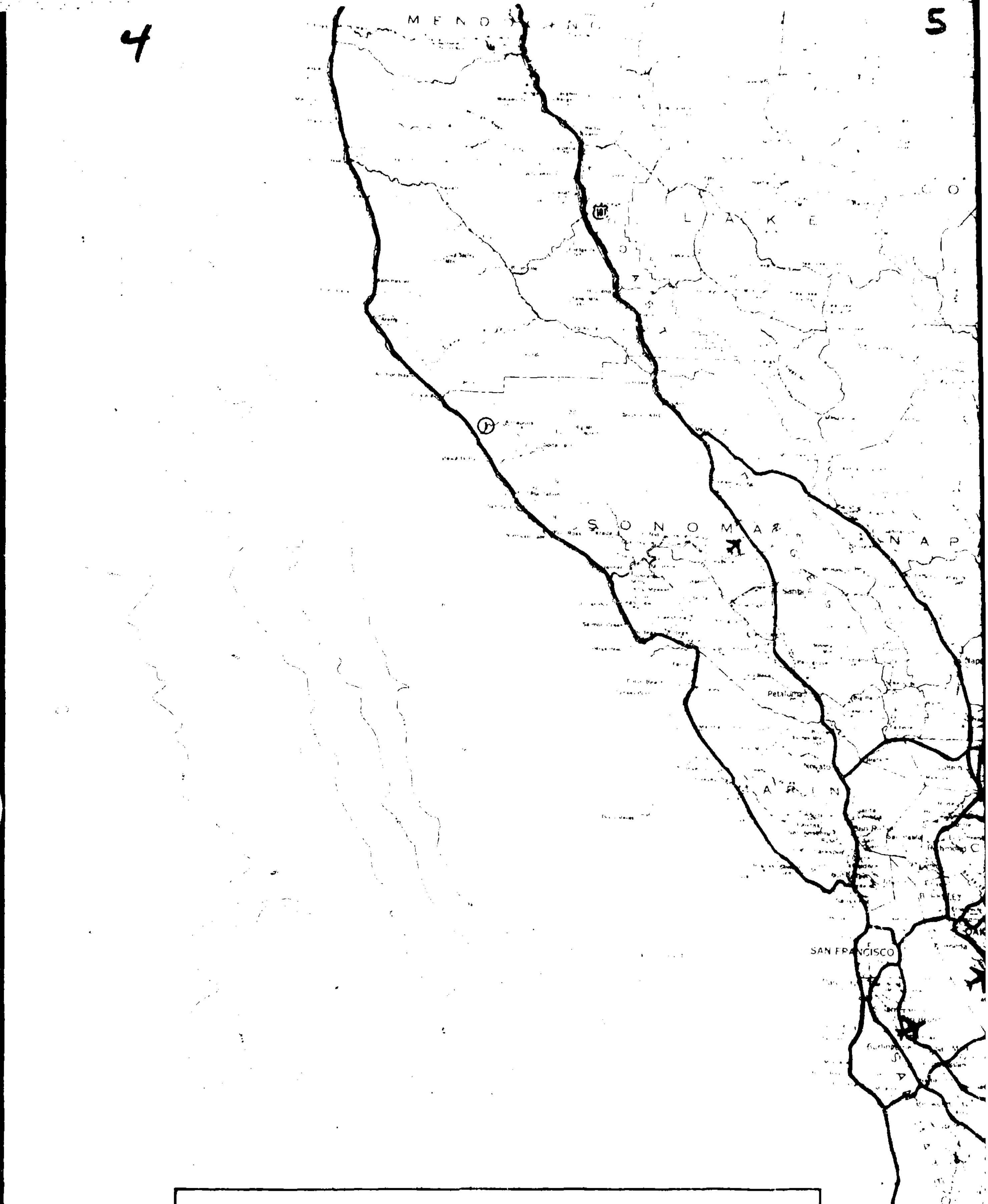

Exhibit 3A
THE HIGHWAY NETWORK AND PRINCIPAL AIRPORTS
Northern California

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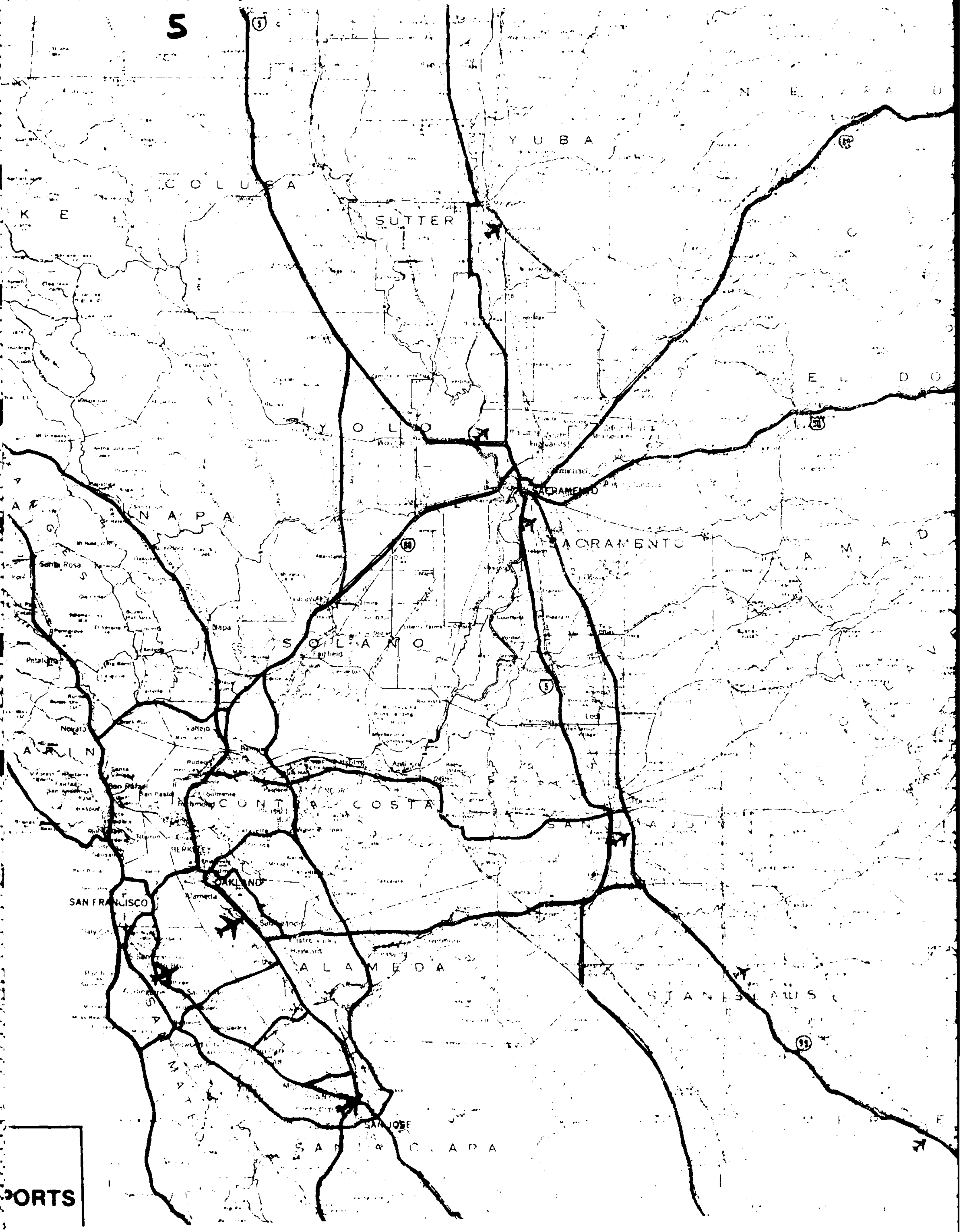

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NAPA
SOLANO
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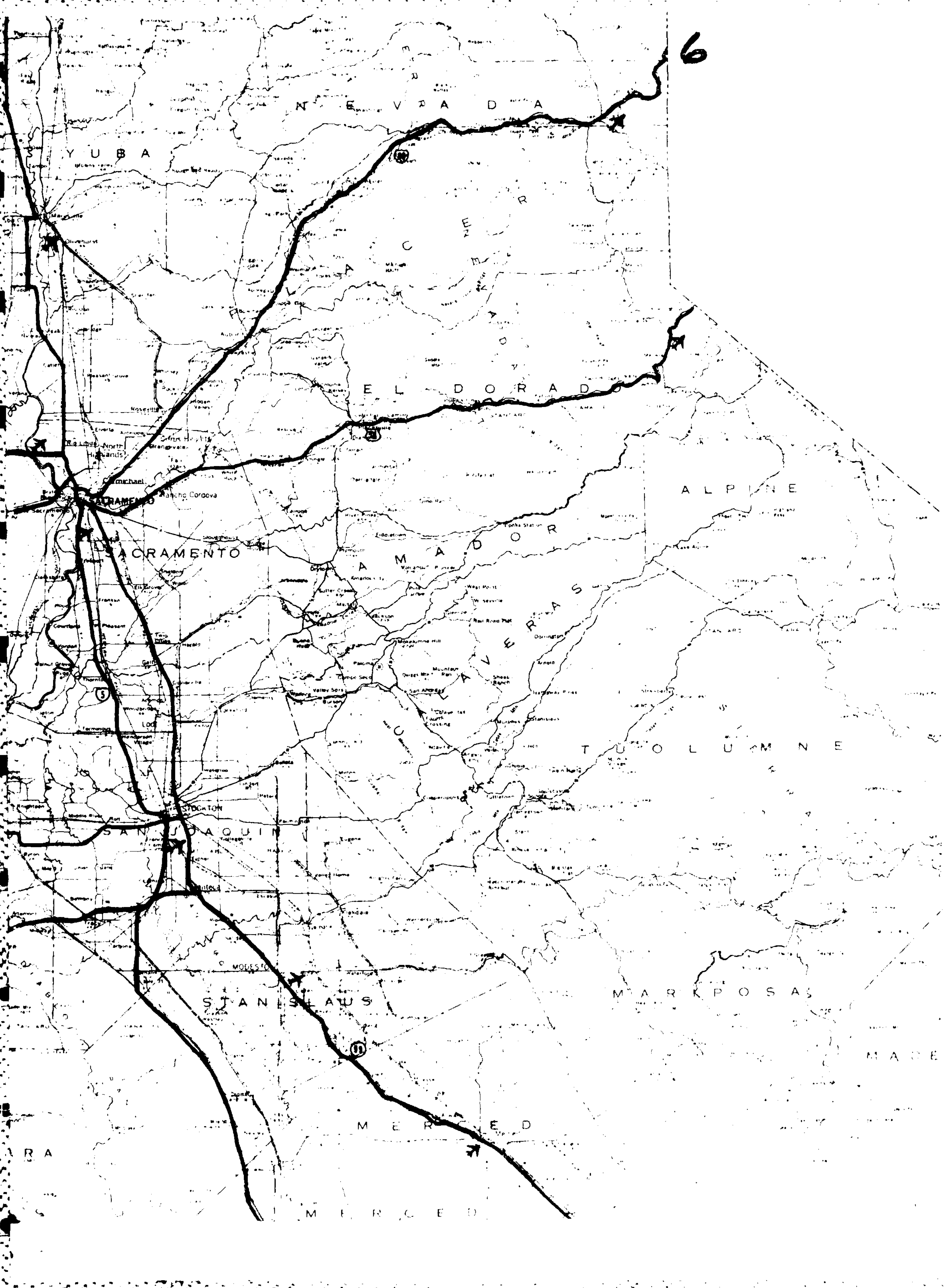
CONTRA COSTA
ALAMEDA
STANISLAUS
Santa Rosa
Petaluma
Novato
Napa
Fairfield
Vallejo
San Rafael
Richmond
OAKLAND
SAN FRANCISCO
Alameda
Hayward
Lodi
SAN JOSE

PORTS

6



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Carmichael
North Highlands
Roseville

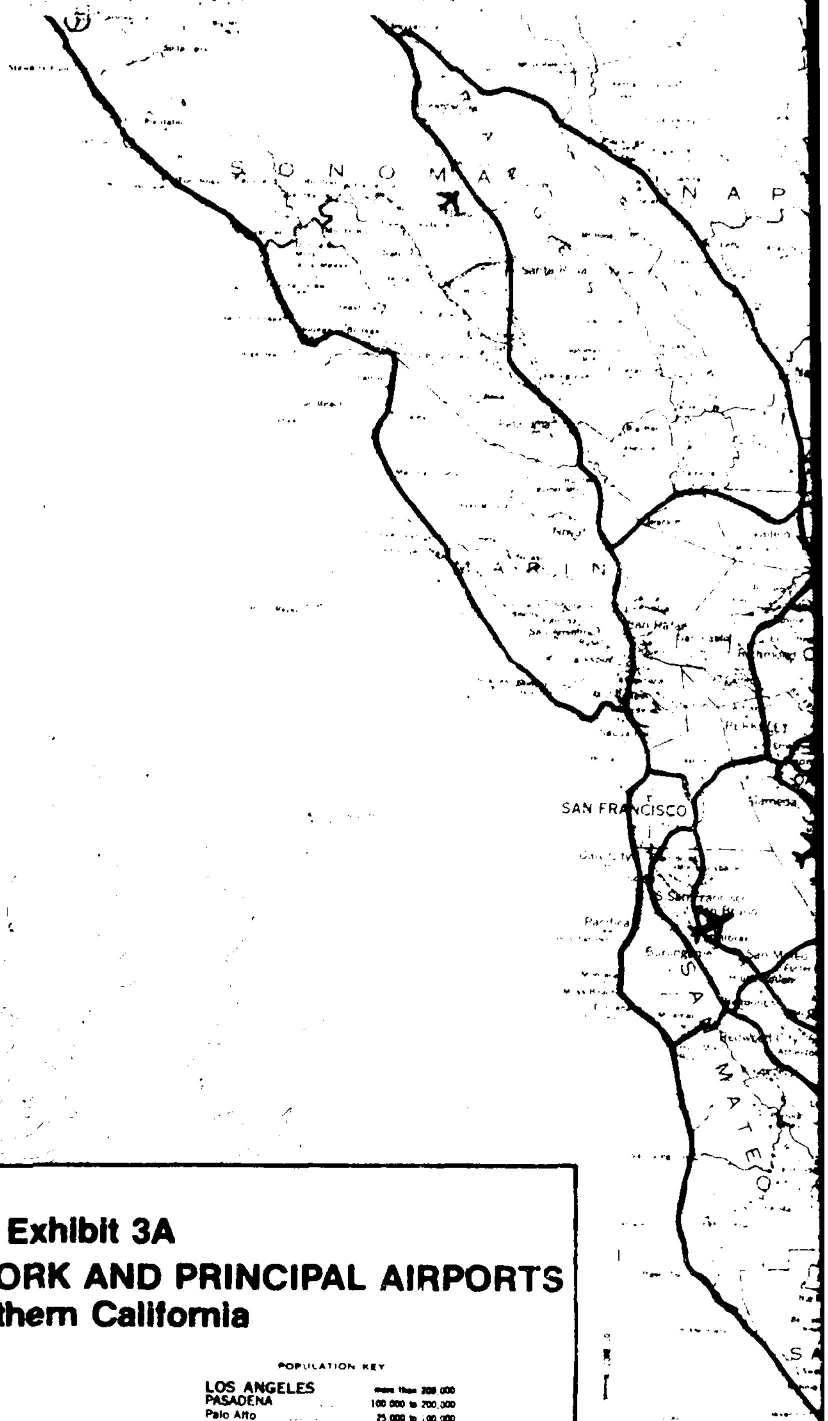

Exhibit 3A
THE HIGHWAY NETWORK AND PRINCIPAL AIRPORTS
Northern California

LEGEND

- State capital
- County seat
- City, town, or village
- Scheduled service airport
- Built-up area shown for towns over 25,000 population

POPULATION KEY

LOS ANGELES	more than 200,000
PASADENA	100,000 to 200,000
Palo Alto	25,000 to 100,000
Folsom	5,000 to 25,000
Bishop	less than 5,000

Population indicated by size of letters

Scale

Miles

Kilometres

BASE MAP: Compiled, edited, and published by the Geological Survey. 1927 North American datum

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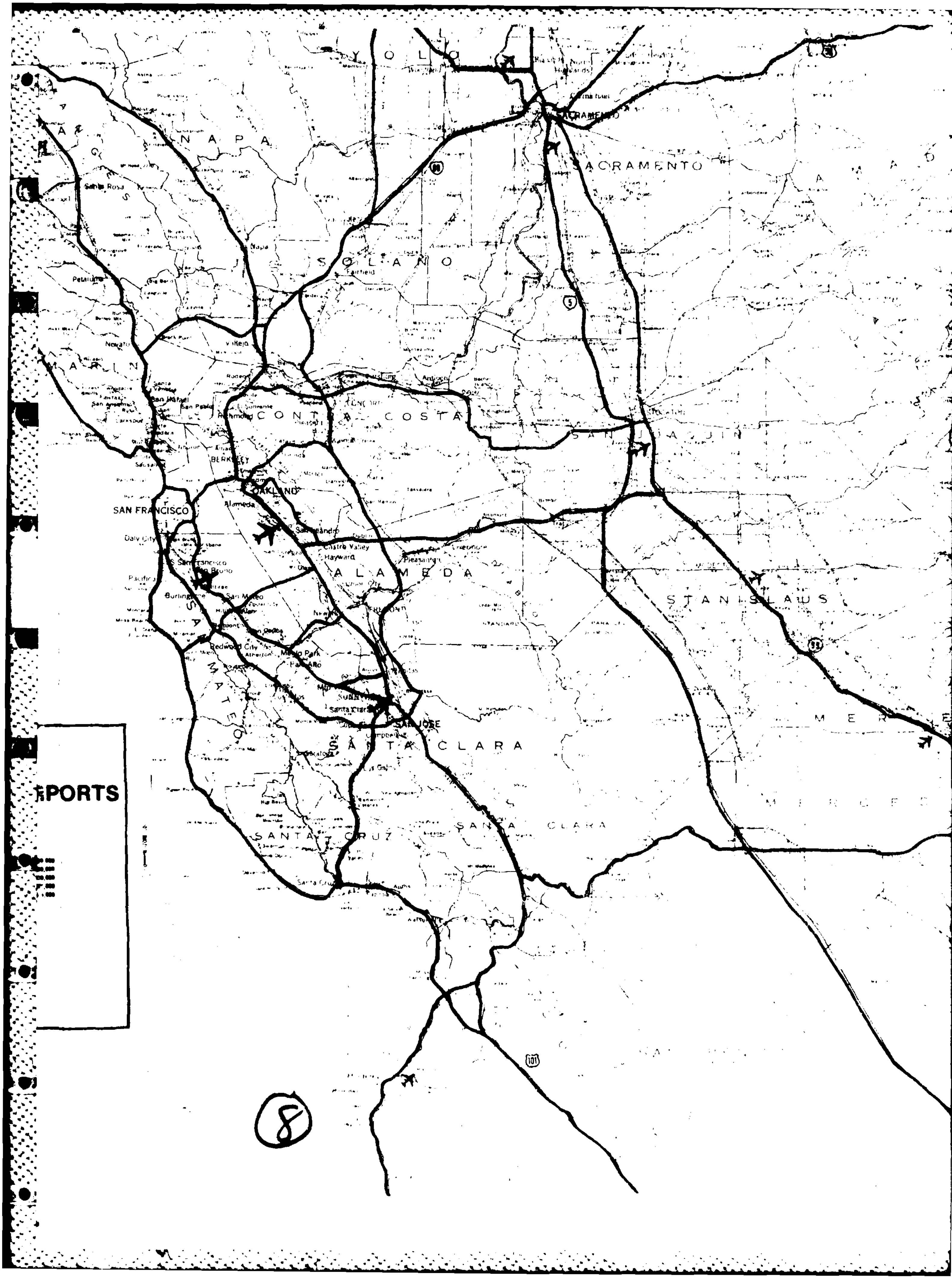

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SOLANO
MARIN
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ALAMEDA
STANISLAUS
SANTA CLARA
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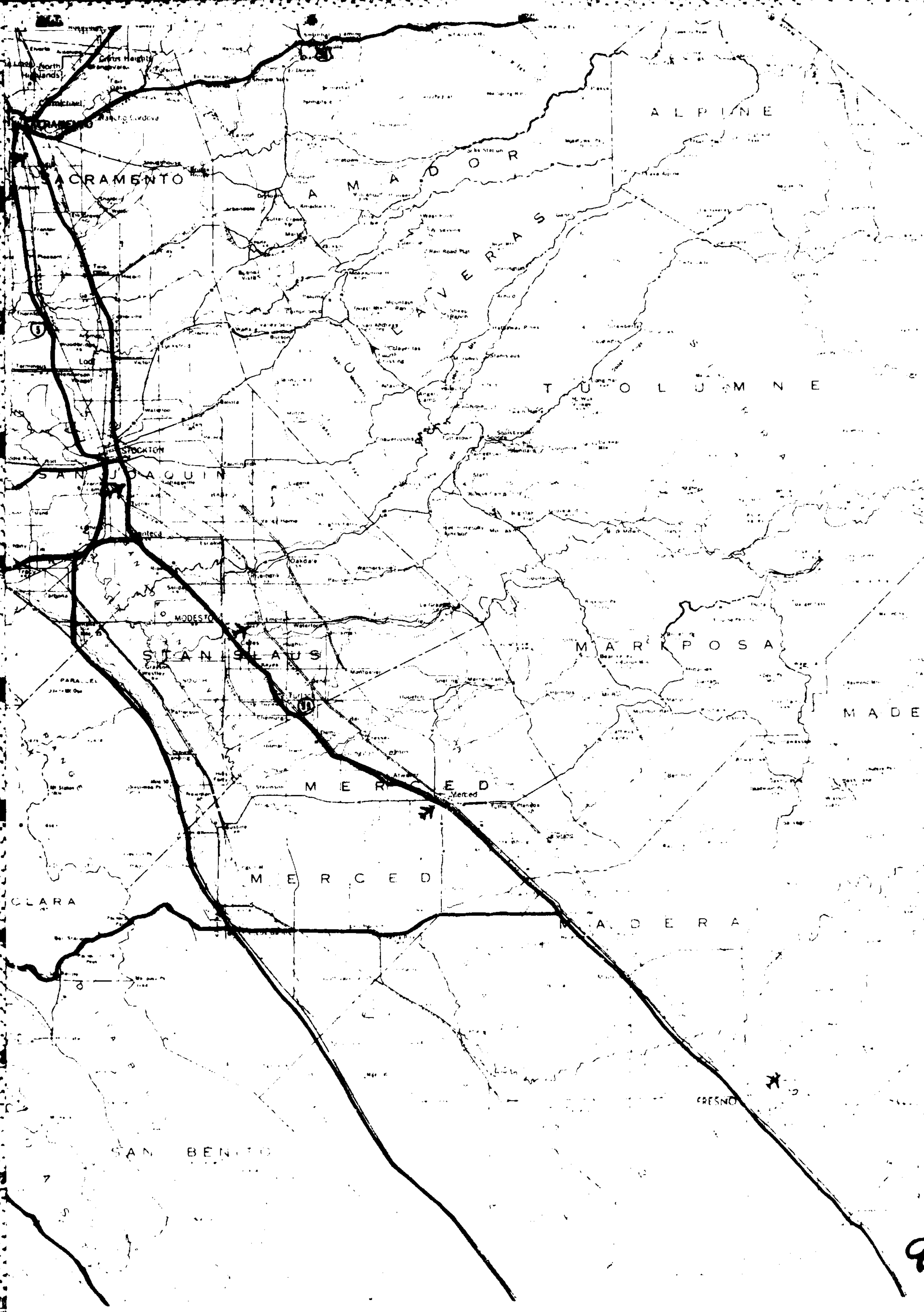
Santa Rosa
Petaluma
Novato
Vallejo
Fairfield
San Rafael
San Pablo
Richmond
BERKELEY
OAKLAND
Alameda
SAN FRANCISCO
Daly City
San Bruno
Burlingame
San Mateo
Redwood City
Atherton
Menlo Park
Palo Alto
Santa Clara
SAN JOSE
Campbell
Los Gatos
Santa Cruz
Castro Valley
Hayward
Pleasanton
Antioch
PORTS

8



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STOCKTON
SAN JOAQUIN
MODESTO
STANISLAUS
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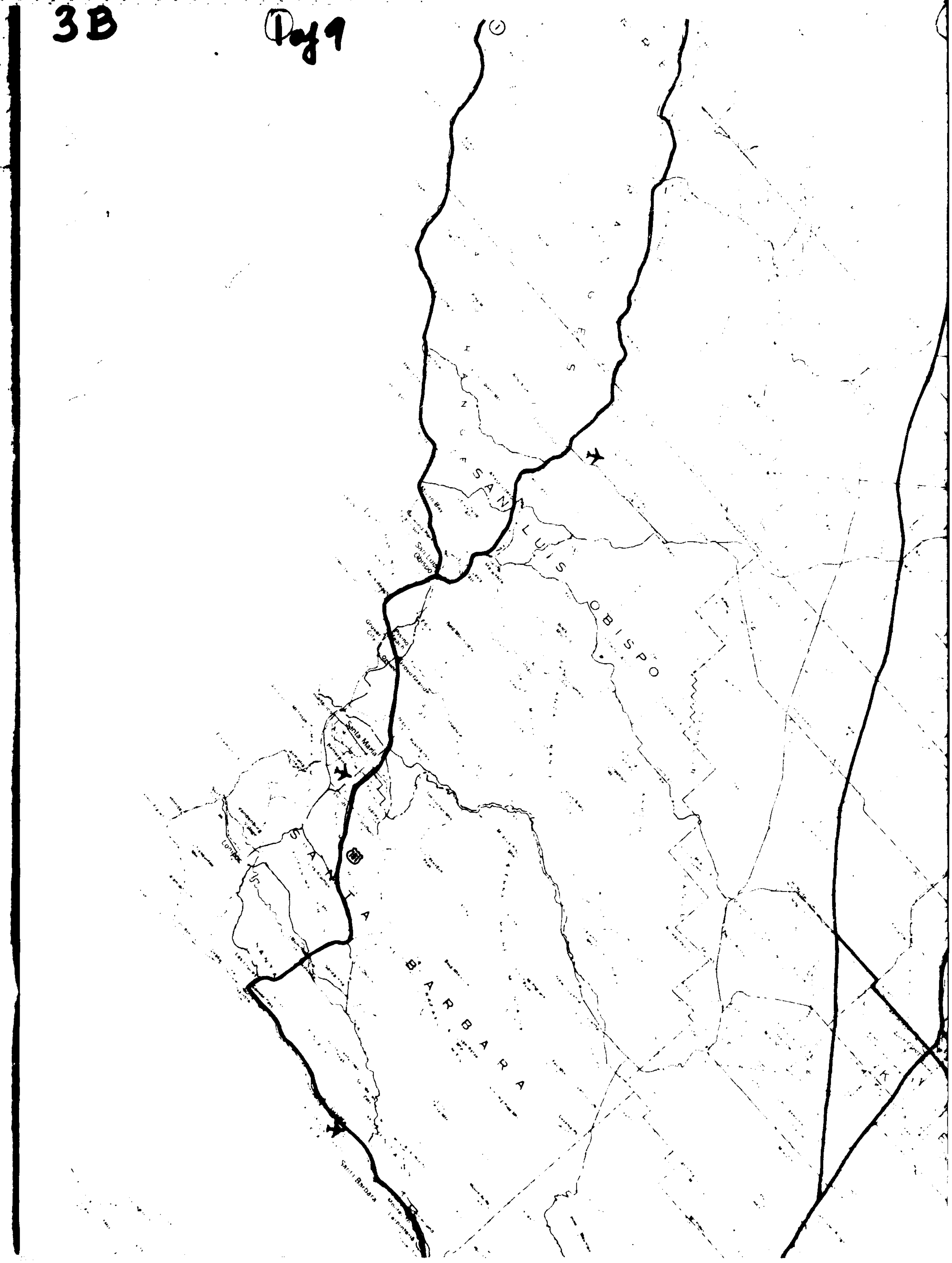
Merced
MERCED
MADERA
CLARA
FRESNO

3A
9 of 9

3B

Day 9



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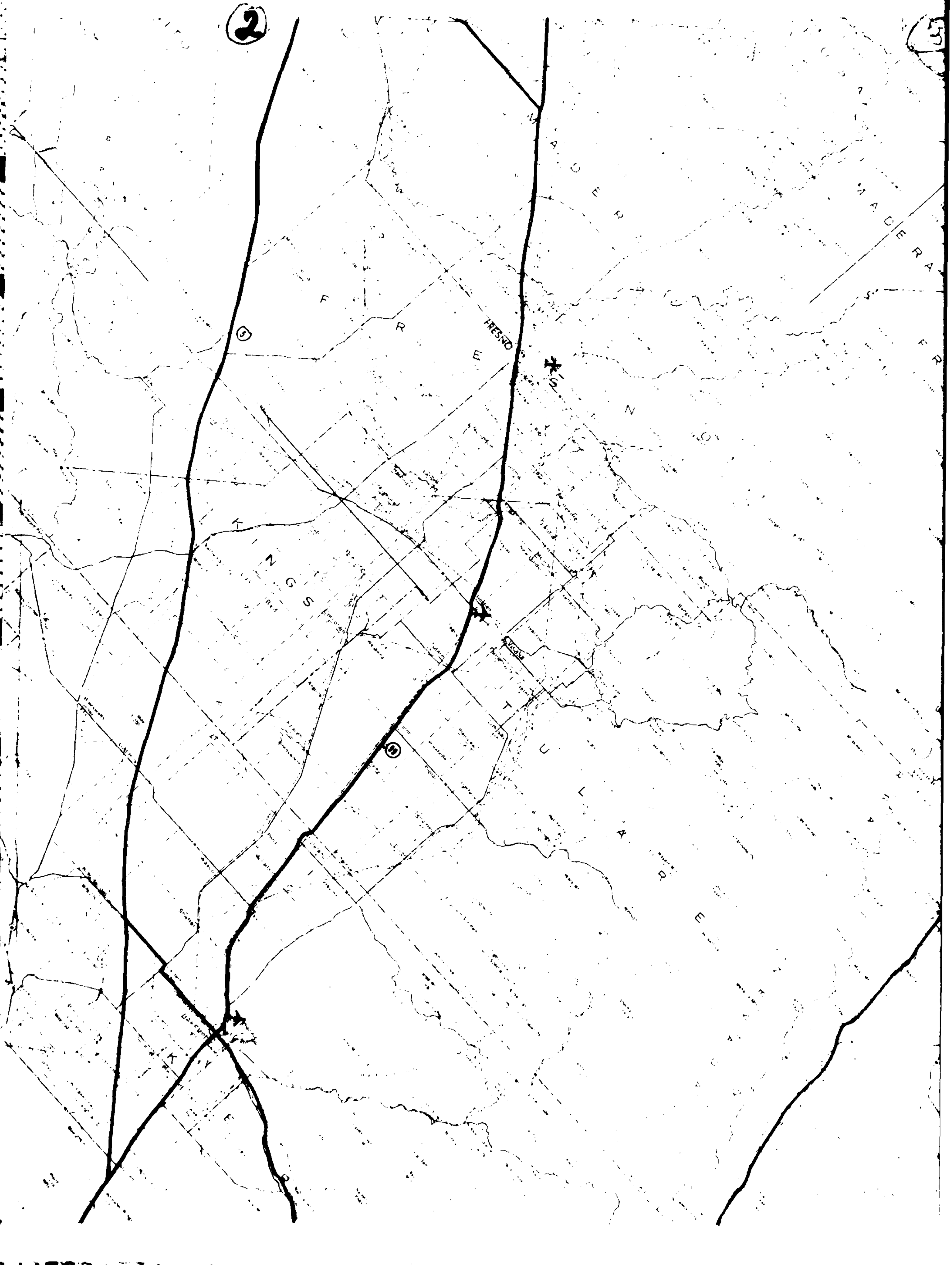
San Luis Obispo
Santa Maria
Lompoc
SANTA BARBARA
Santa Barbara



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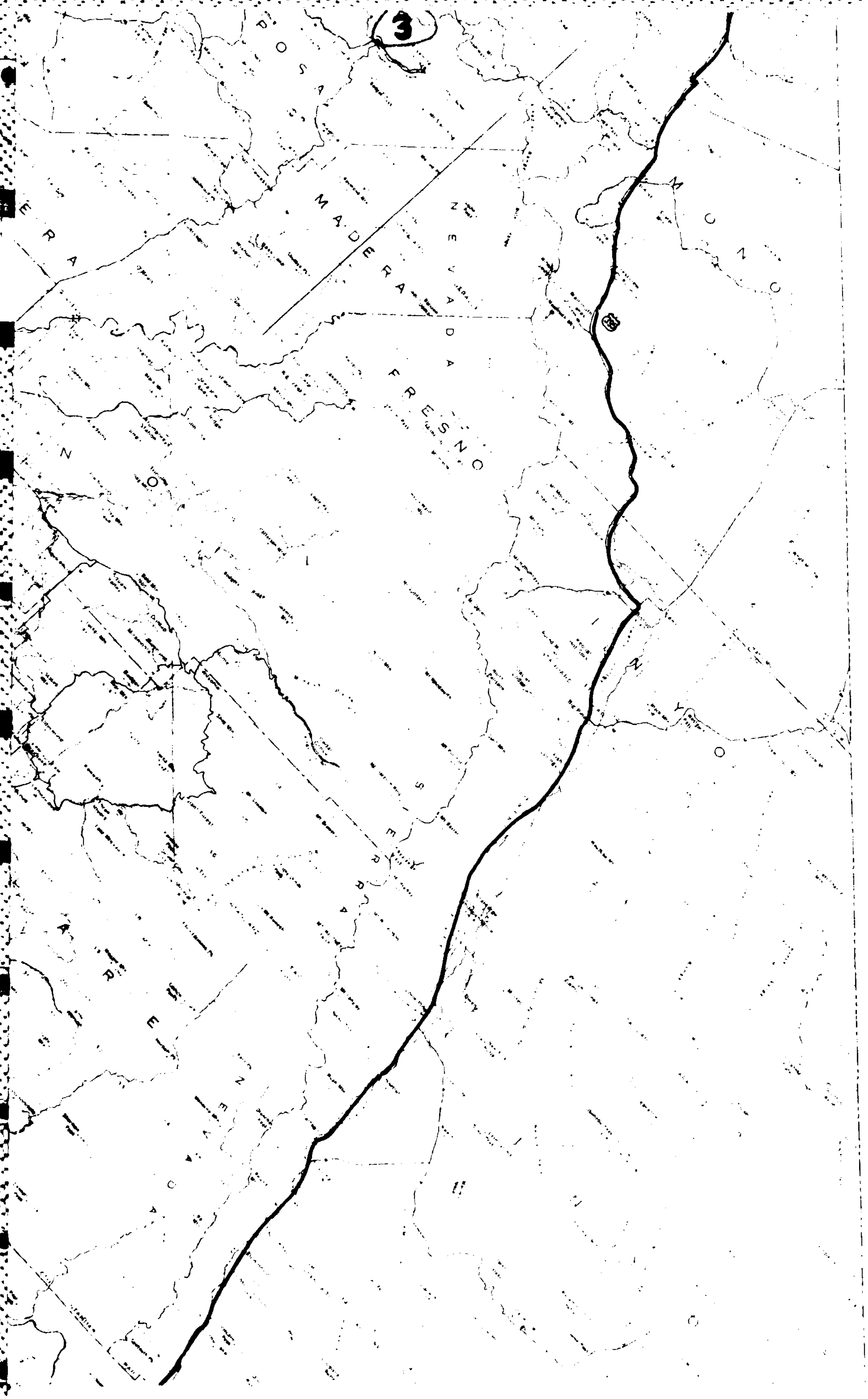

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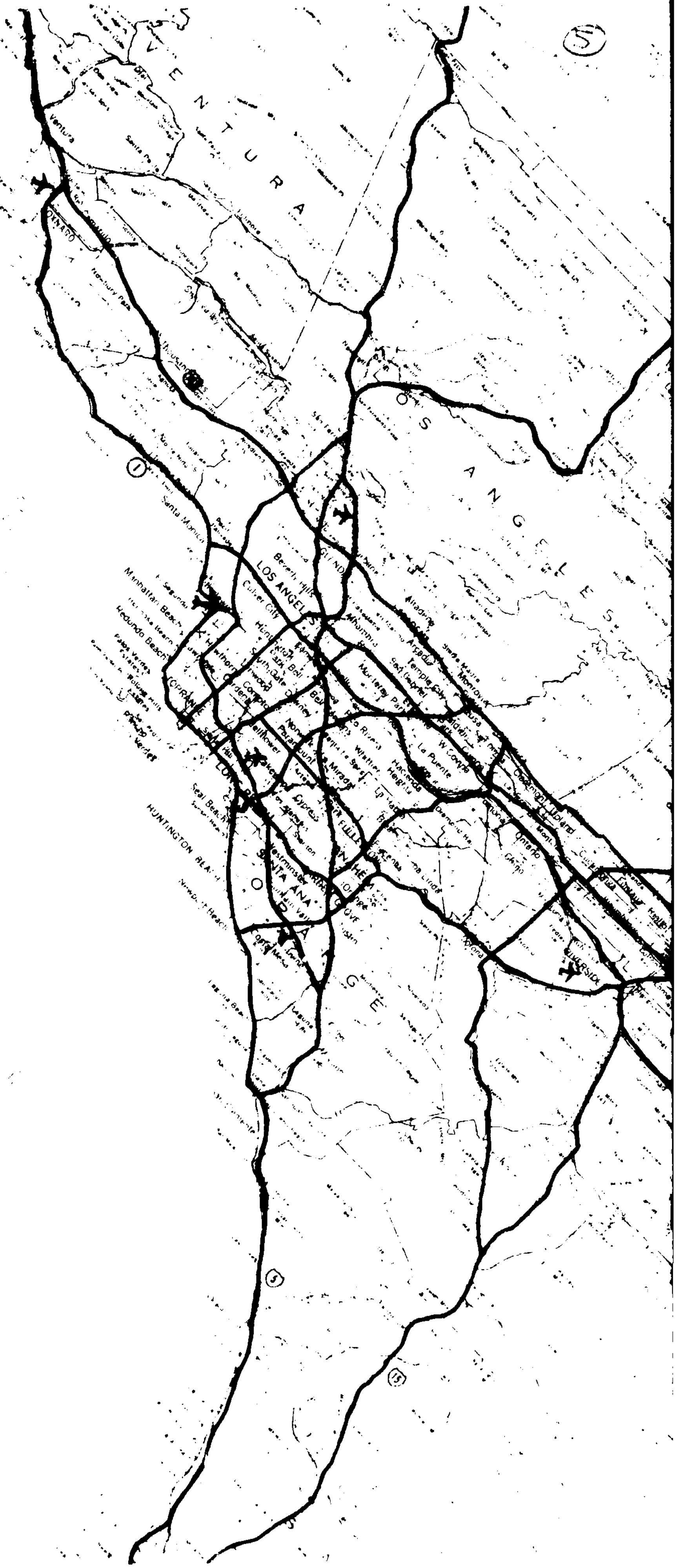

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VENTURA
Ventura
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ORANGE
Santa Monica
Manhattan Beach
Redondo Beach
TORRANCE
Culver City
Beverly Hills
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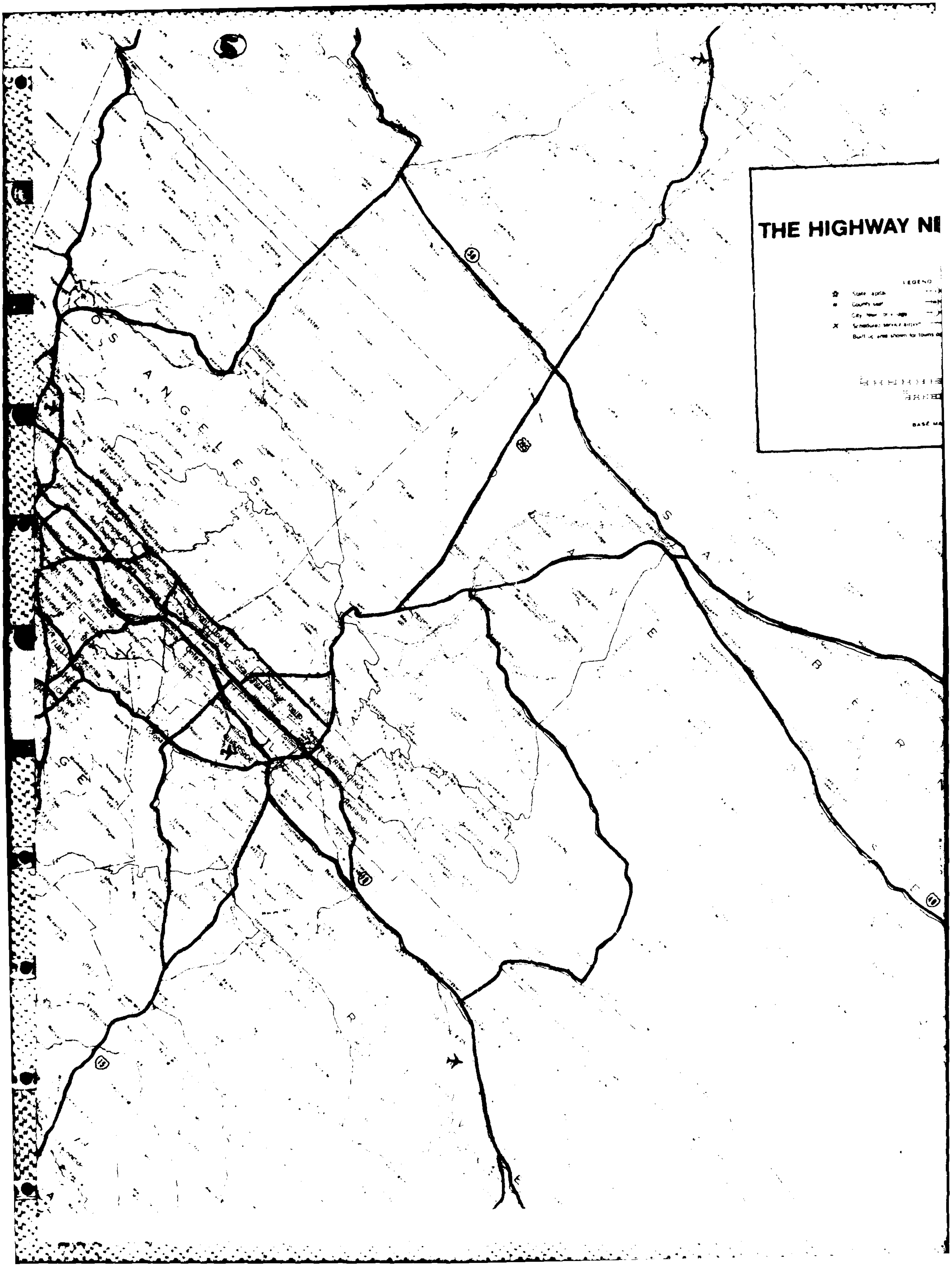
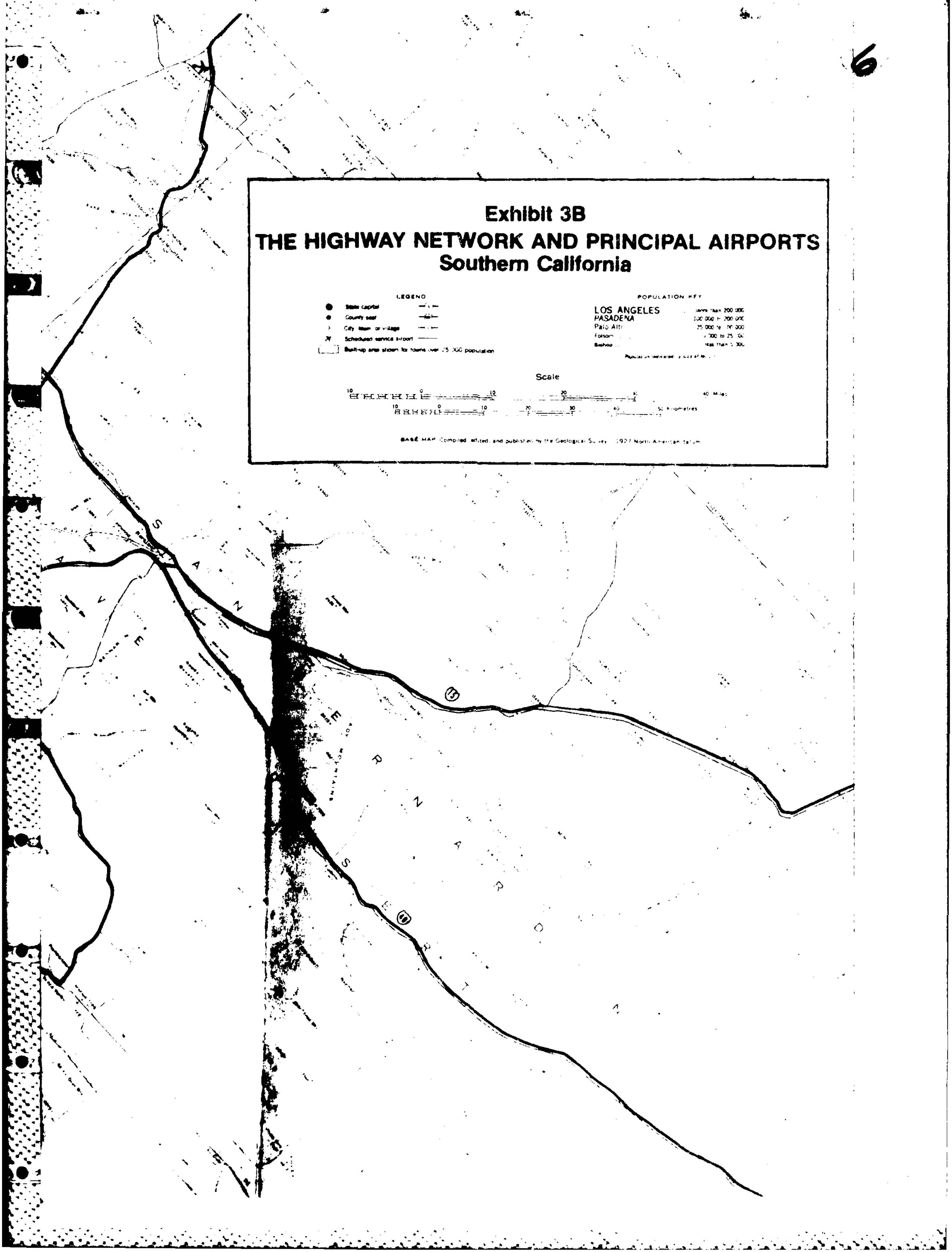
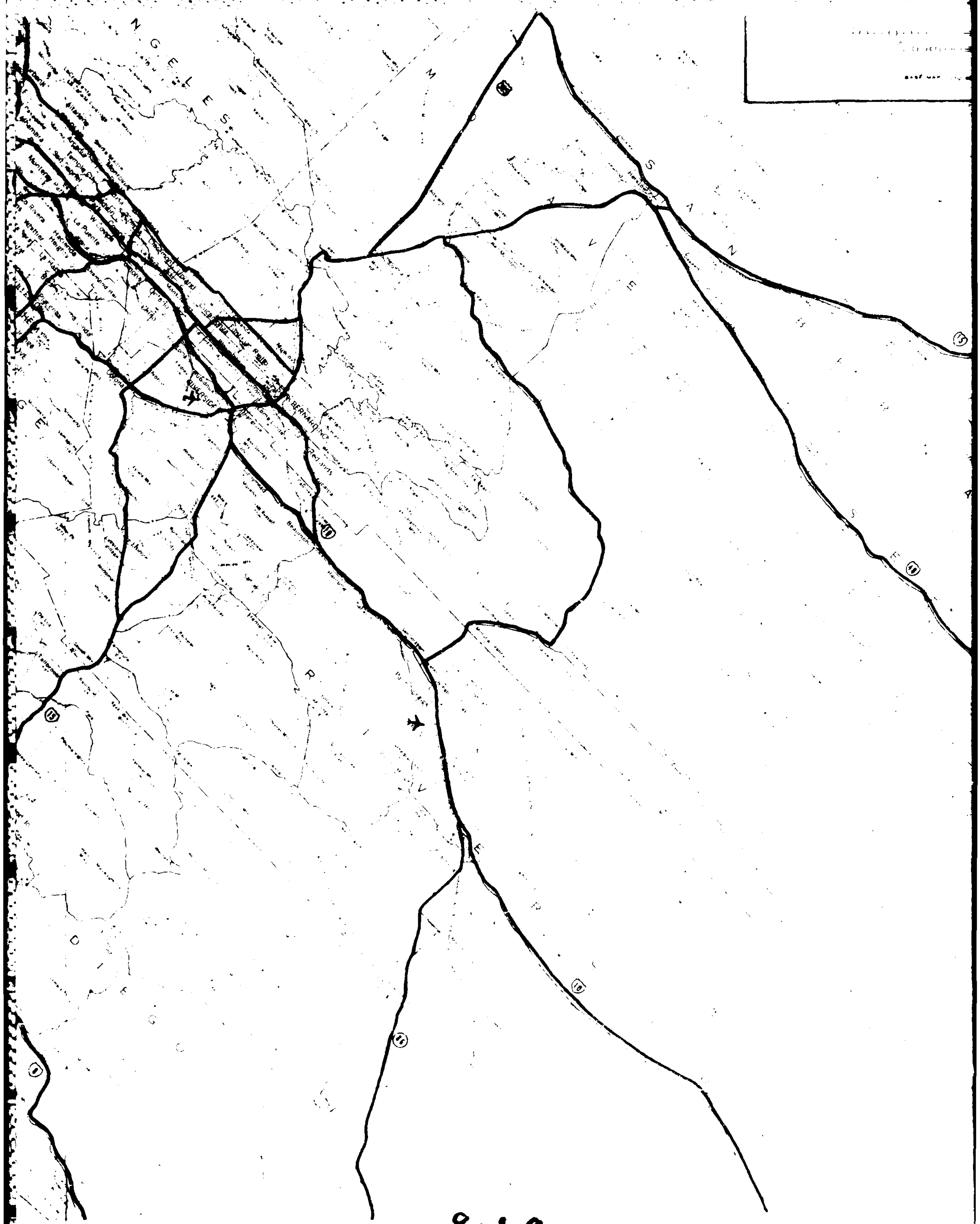
Temple City
Monterey Park
La Puente
Ontario
Seal Beach
HUNTINGTON BEACH
SANTA ANA
Westminster
Newport Beach



THE HIGHWAY NE
LEGEND


6
Exhibit 3B
THE HIGHWAY NETWORK AND PRINCIPAL AIRPORTS
Southern California
LEGEND
State capital
County seat
City, town, or village
Scheduled service airport
Built-up area shown for towns over 25,000 population
POPULATION KEY
LOS ANGELES
PASADENA
Palo Alto
Folsom
Bishop
Scale
40 Miles
50 Kilometres
BASE MAP Compiled, edited, and published by the Geological Survey
S A N
E R N A R D I N O
15
10

LOS ANGELES
SANTA ANA


RIVERSIDE
Redlands
Beaumont
La Puente
Whittier
Temple City

8 of 9

AD-A143 554 CALIFORNIA EARTHQUAKE RESIDUAL TRANSPORTATION CAPABILITY STUDY(U) SYSTAN INC LOS ALTOS CA P S JONES DEC 83 SYSTAN-D184 DOT-TSC-RSPA-83-13 3/3

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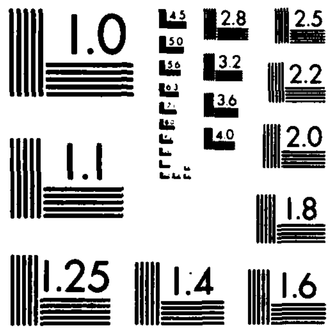
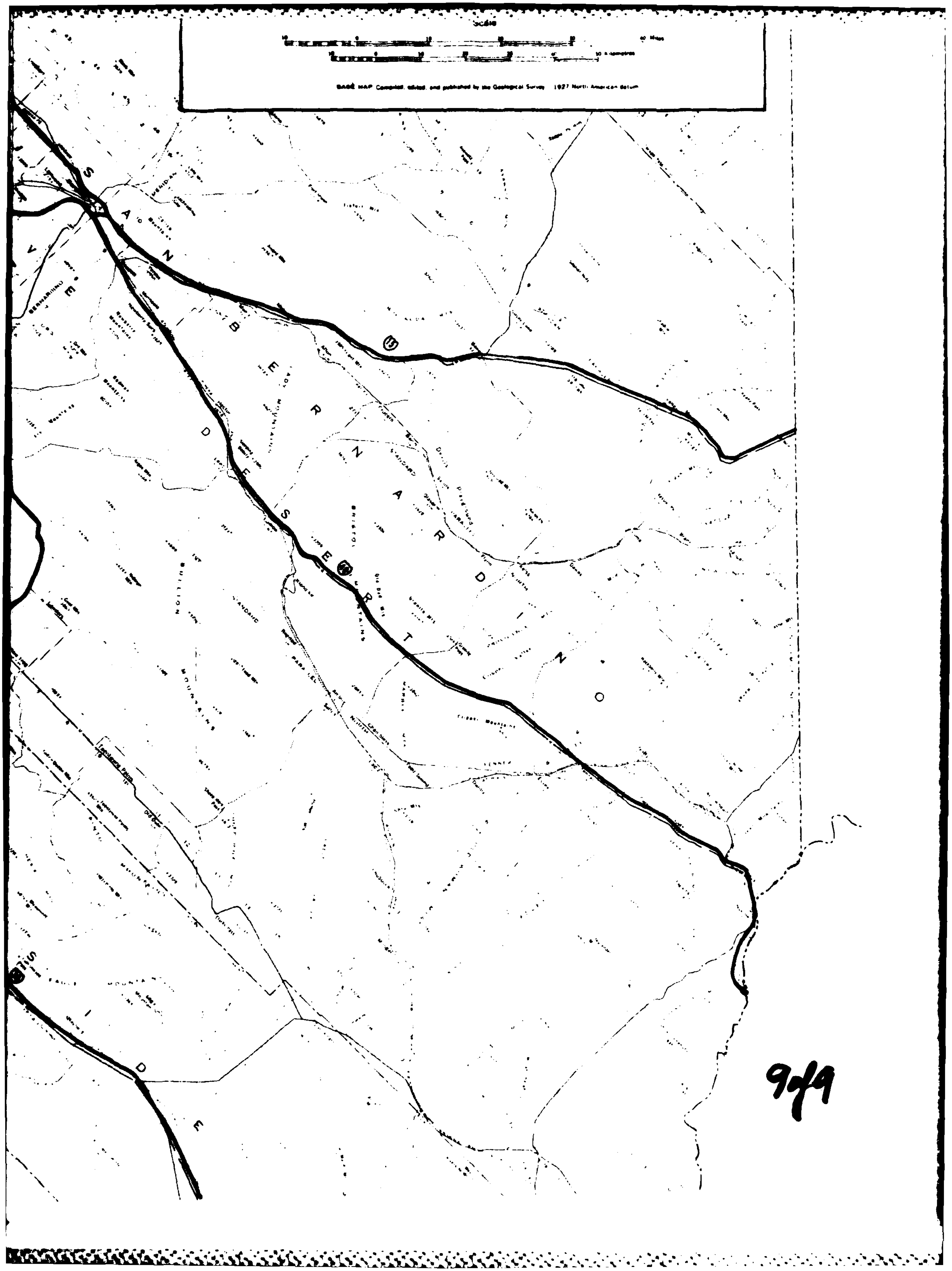
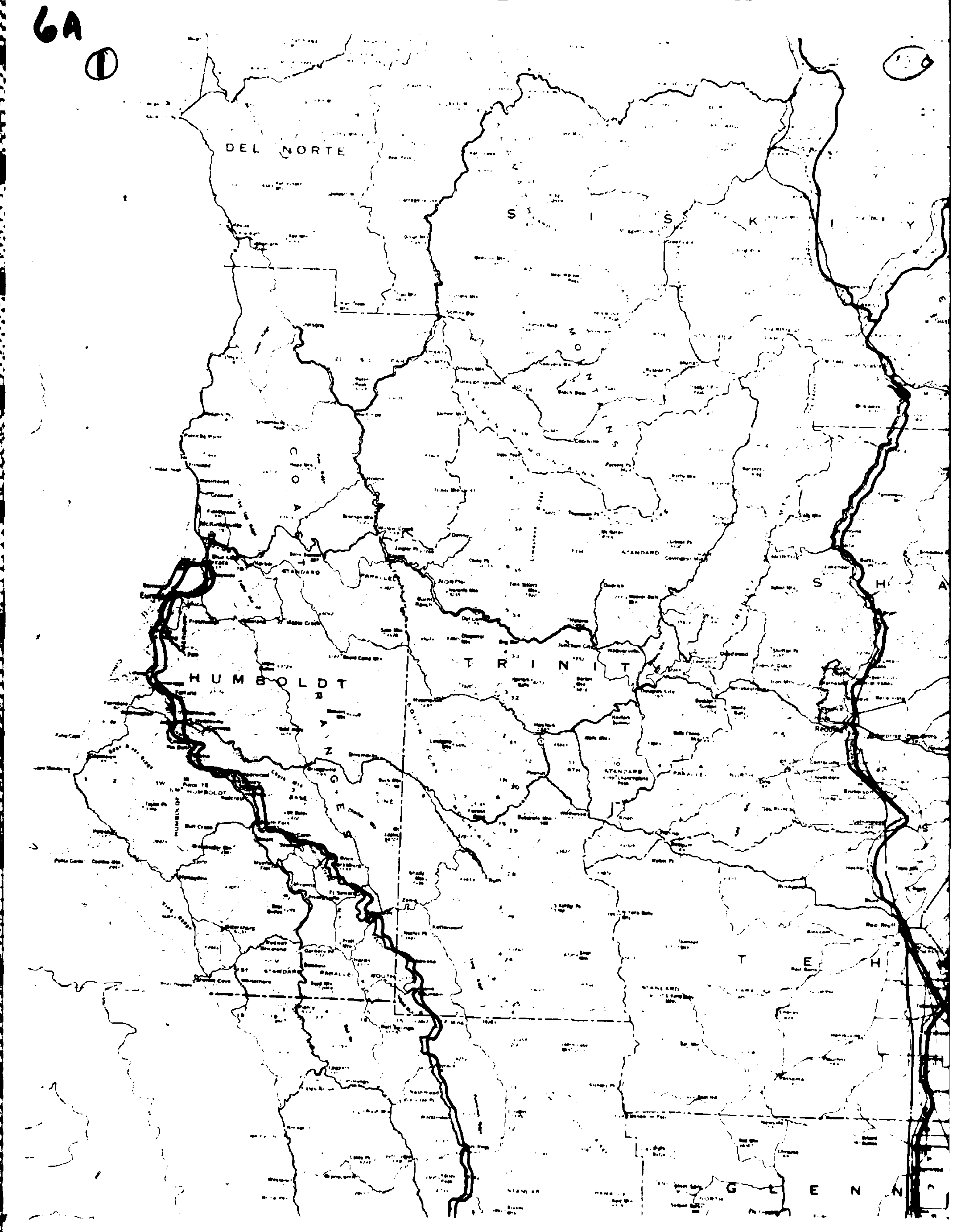


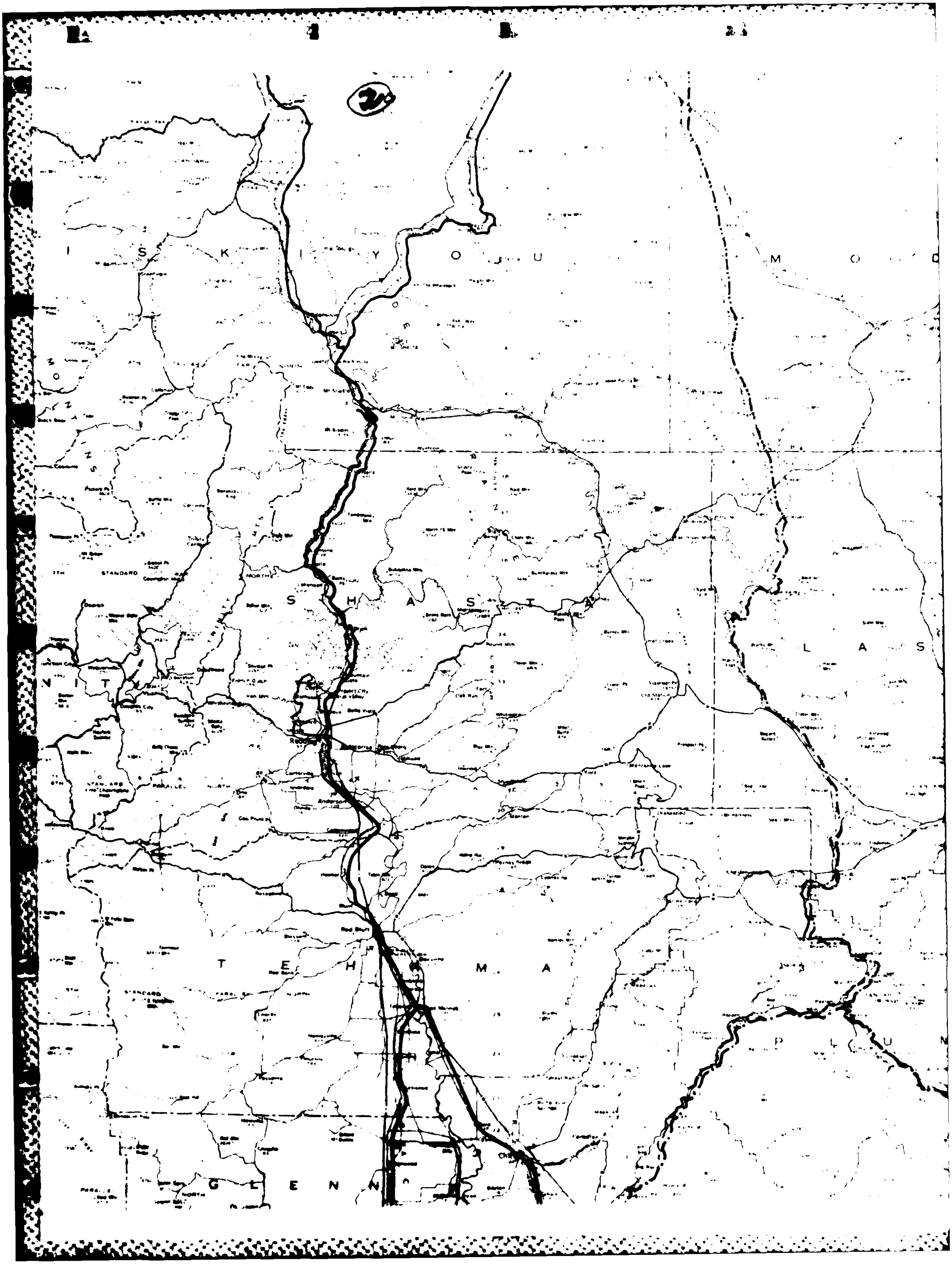
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A


Scale
40 Miles
50 Kilometres
BASE MAP Compiled, edited, and published by the Geological Survey 1927 North American datum
SAN BERNARDINO
Tehachapi Pass
MOUNTAINS
BRISTOL

9 of 9

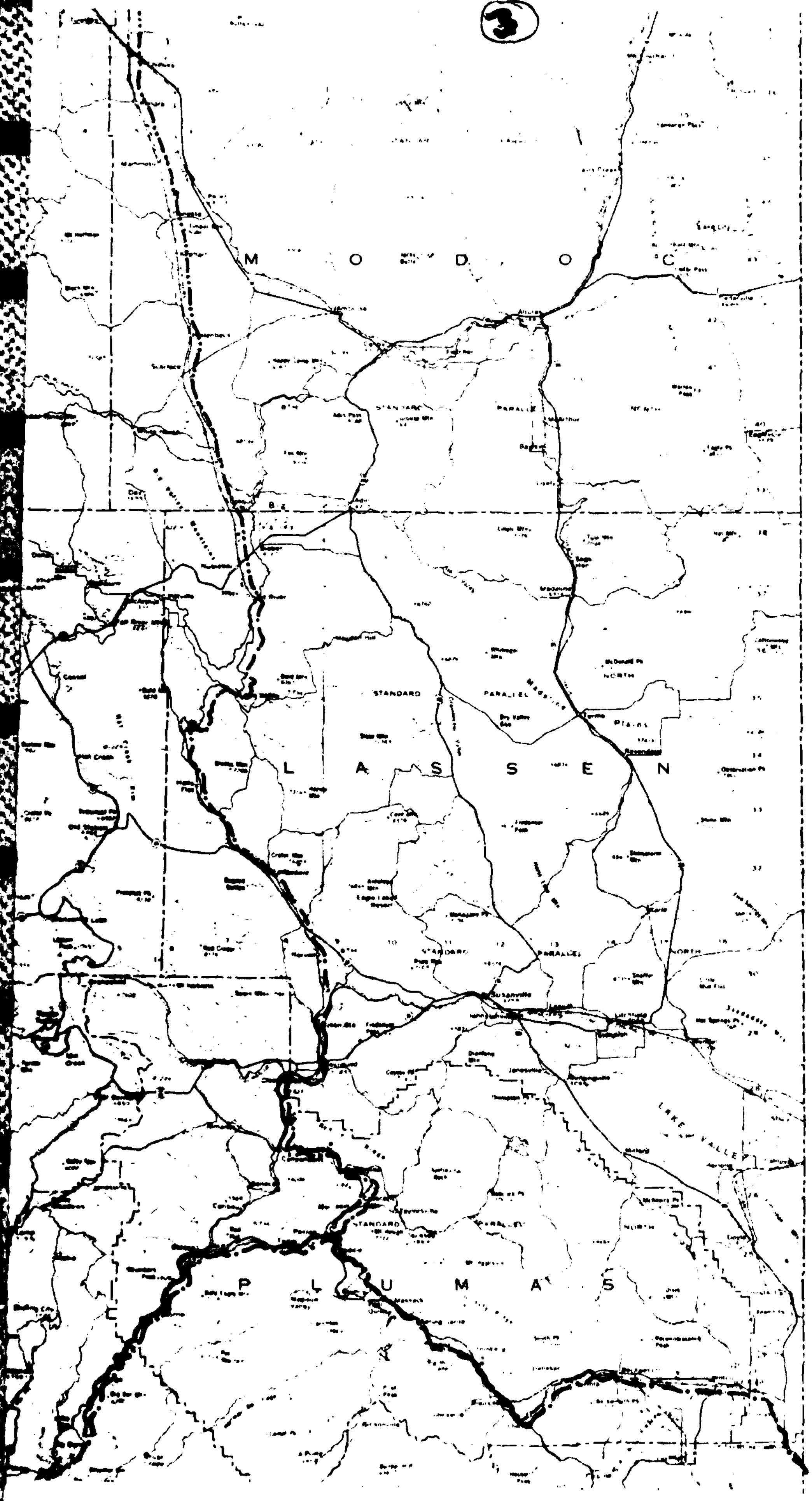


6A
1
DEL NORTE
S I S K I Y
HUMBOLDT
TRINIT
SHA
TEH
GLENN
STANDARD
PARALLEL
NORTH



2
I S K I Y O U
M O D
S H A S T A
L A S
Redding
Anderson
Red Bluff
T E H A M A
P L U M
G L E N N
STANDARD

3



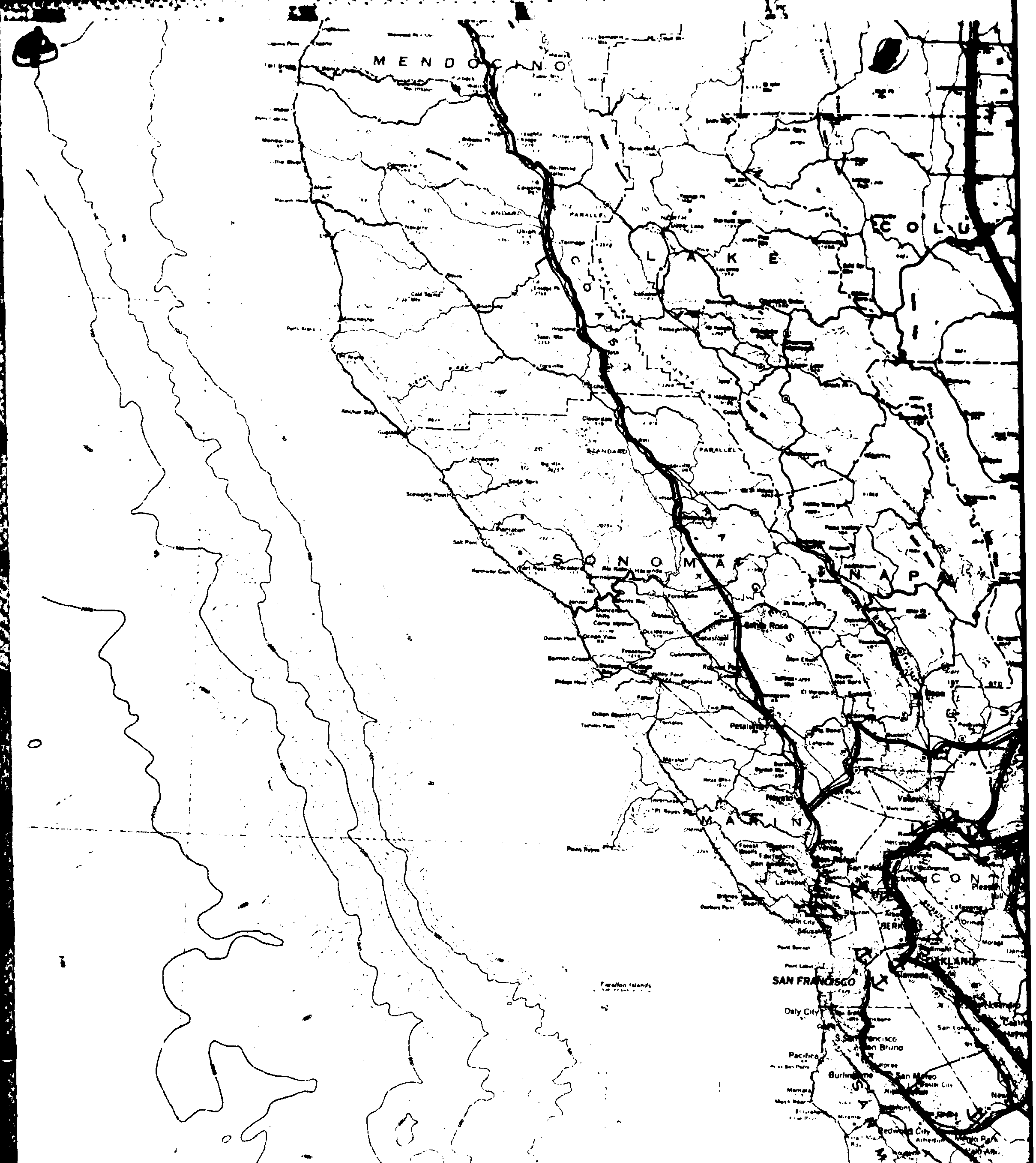
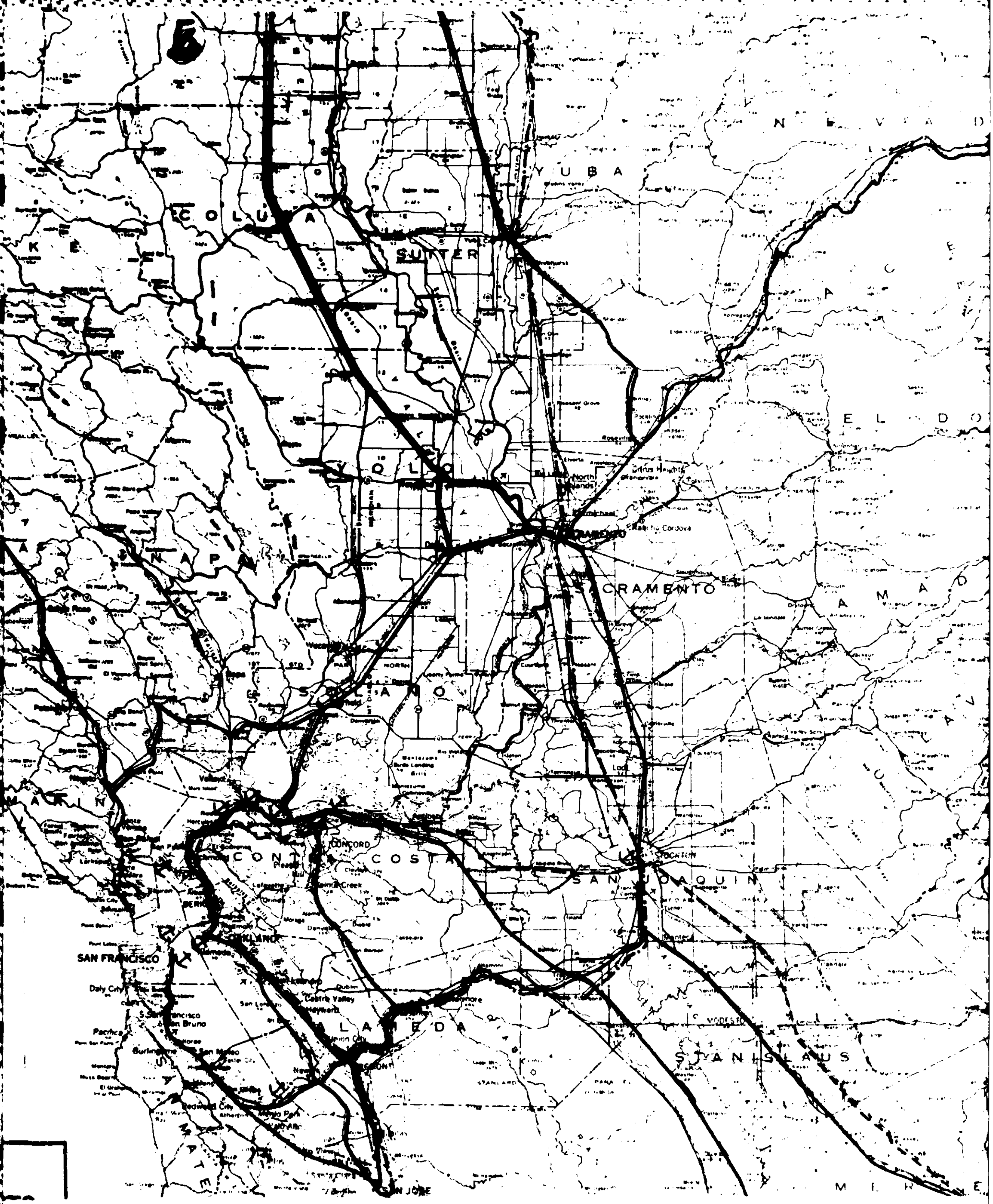


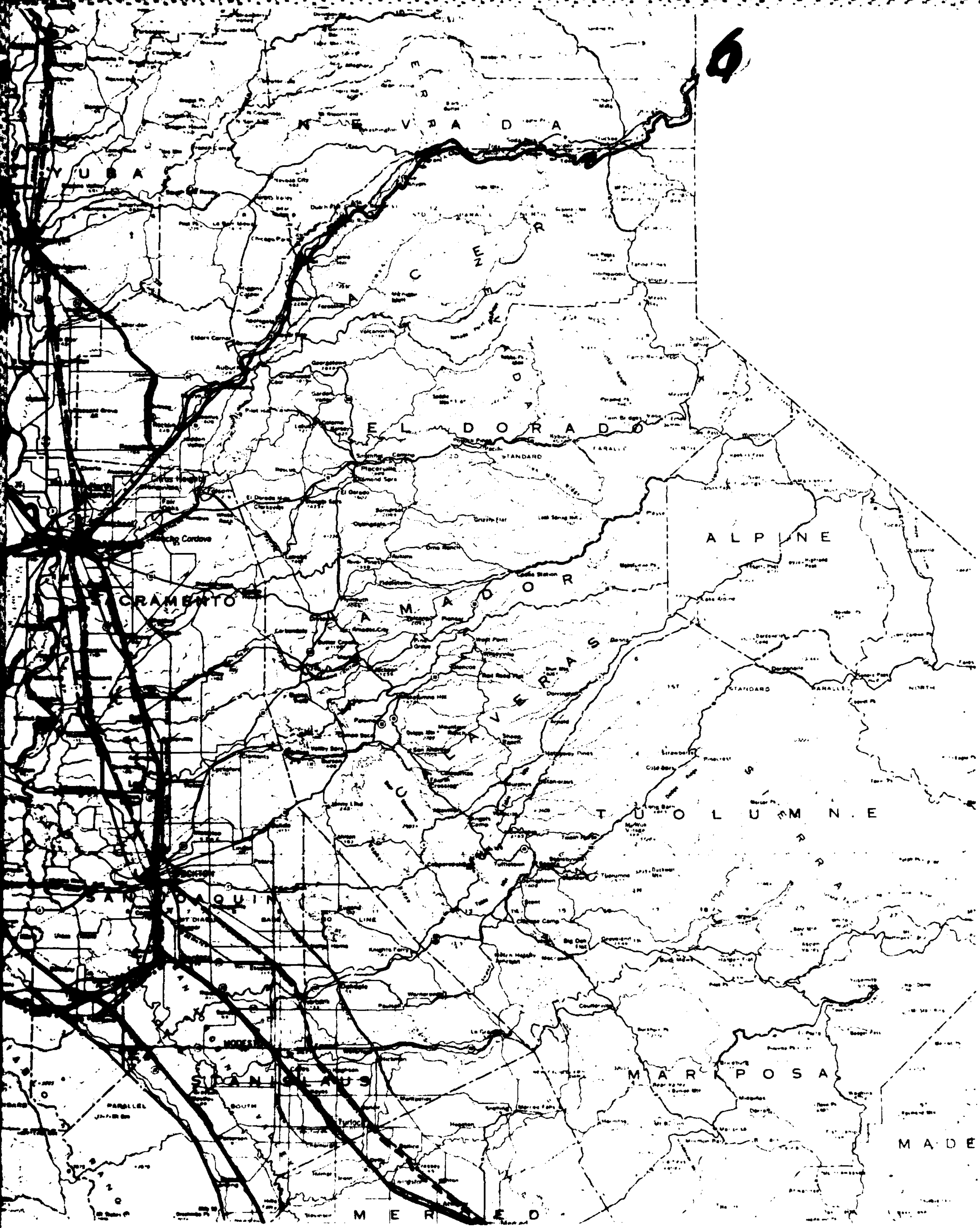
Exhibit 6A

THE RAILROAD NETWORK AND MAJOR PORTS



5
YUBA
SUTTER
SACRAMENTO
SAN JOAQUIN
STANISLAUS
SAN FRANCISCO
OAKLAND
CONCORD
STOCKTON
SAN JOSE
Roseville
North Highlands
Citrus Heights
Rancho Cordova
Lodi
Manteca
Vallejo
Lafayette
Walnut Creek
Orinda
Moraga
Danville
Dublin
Castro Valley
Hayward
Union City
Daly City
S. San Francisco
San Bruno
Pacifica
Burlingame
San Mateo
Redwood City
Menlo Park

6


NEVADA
YUBA
EL DORADO
ALPINE
AMADOR
TUOLUMNE
MARIPOSA
MADE
MERCED
STANDARD
NORTH

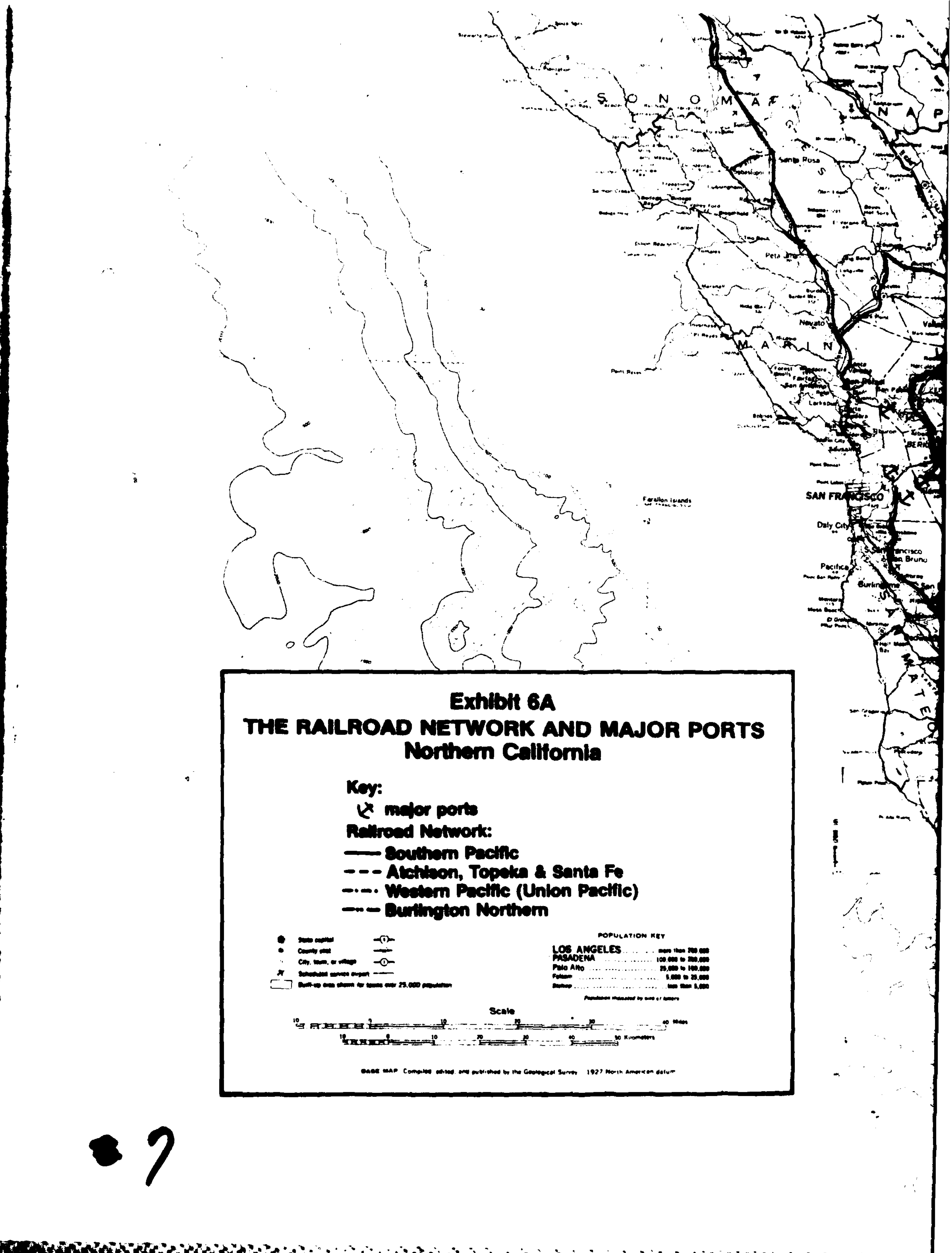


Exhibit 6A
THE RAILROAD NETWORK AND MAJOR PORTS
Northern California

Key:
major ports
Railroad Network:
—— Southern Pacific
- - - Atchison, Topeka & Santa Fe
-·-· Western Pacific (Union Pacific)
-··- Burlington Northern

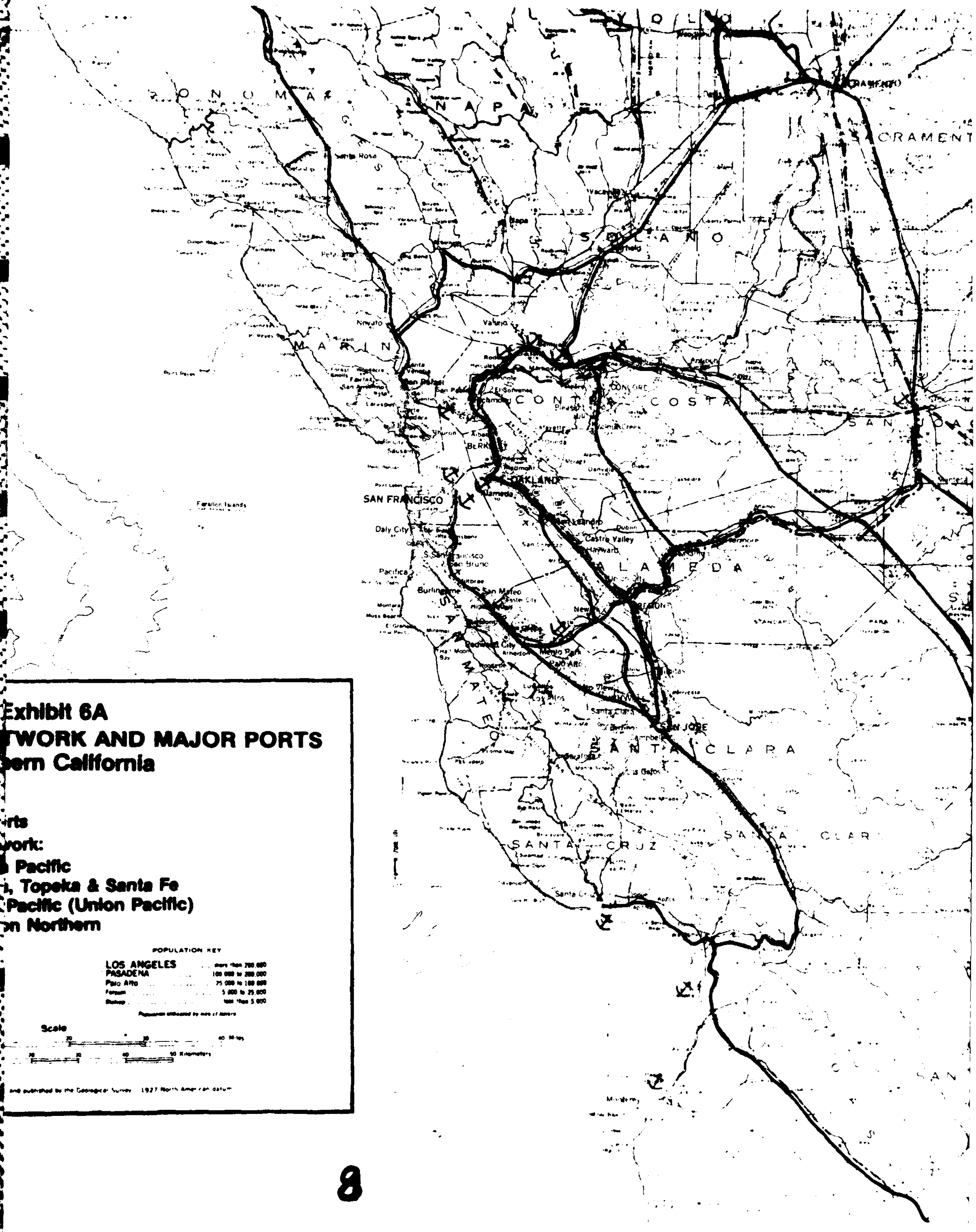
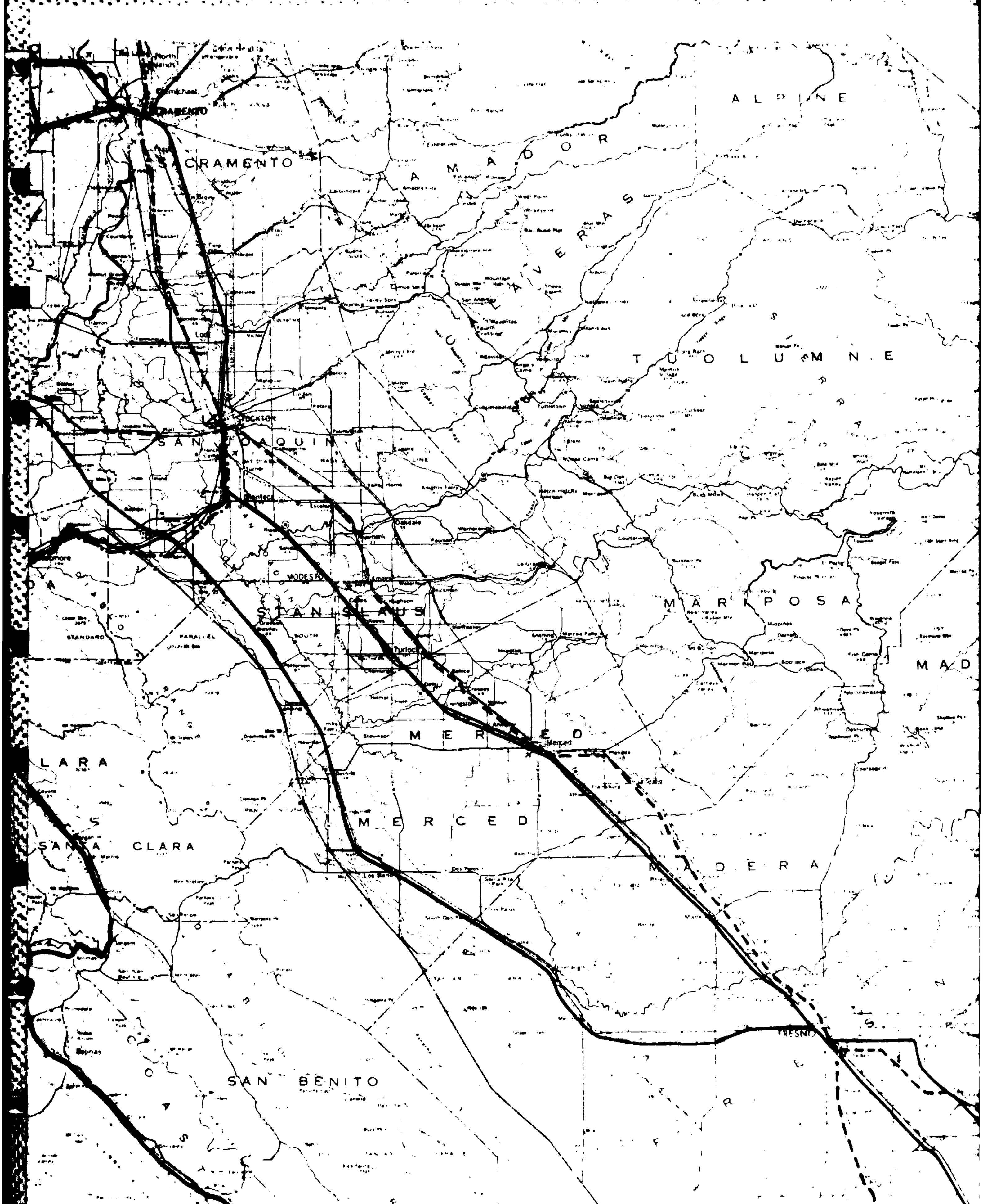


Exhibit 6A
TWORK AND MAJOR PORTS
ern California

rts
work:
Pacific
, Topeka & Santa Fe
Pacific (Union Pacific)
n Northern


ALPINE
AMADOR
SACRAMENTO
CALAVERAS
TUOLUMNE
SIERRA
STOCKTON
SAN JOAQUIN
MODESTO
STANISLAUS
Turlock
MARIPOSA
MAD
MERCED
Merced
MERCED
MADERA
LARA
SANTA CLARA
SAN BENITO
FRESNO

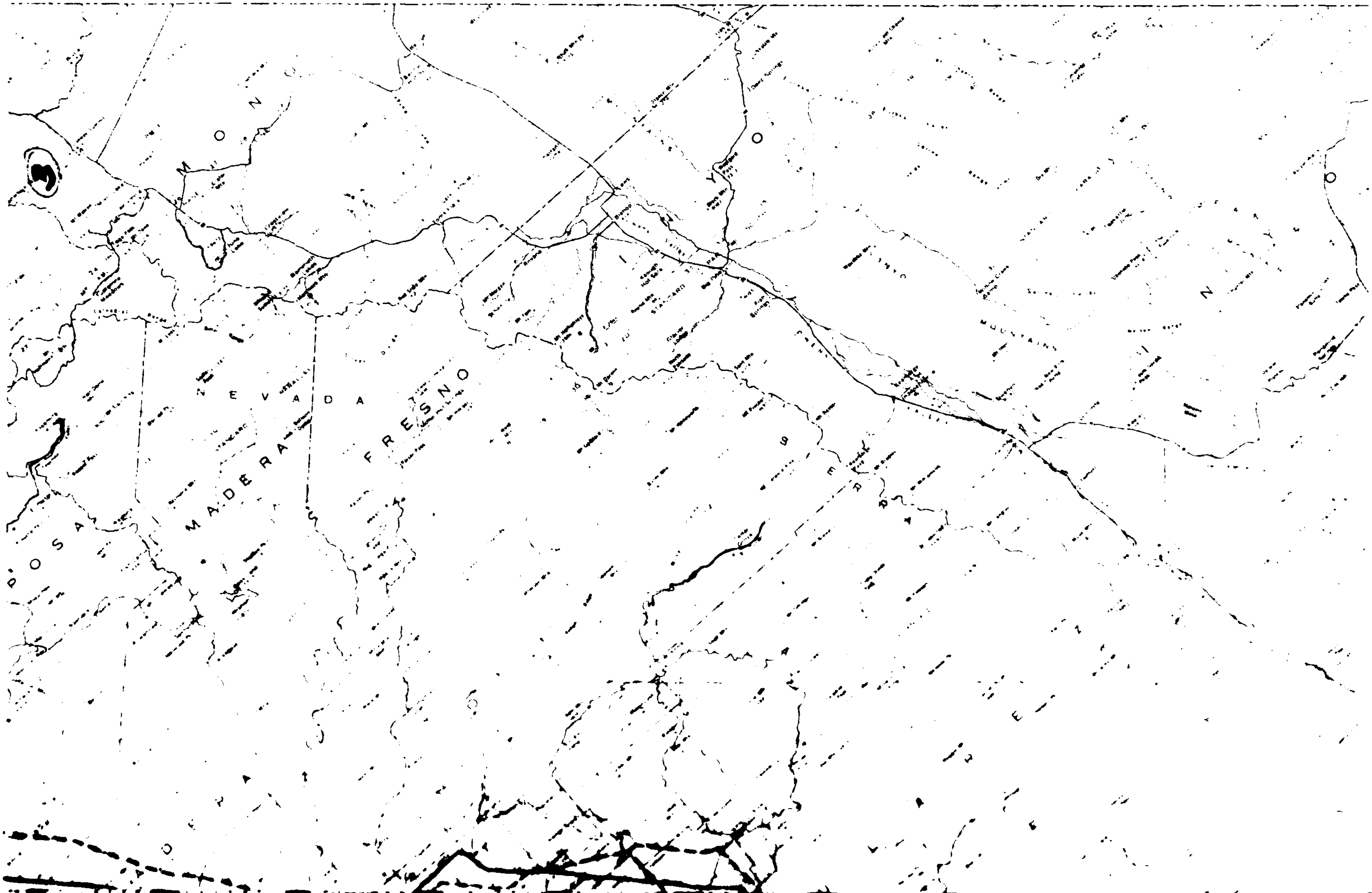
6A - - 949

6B

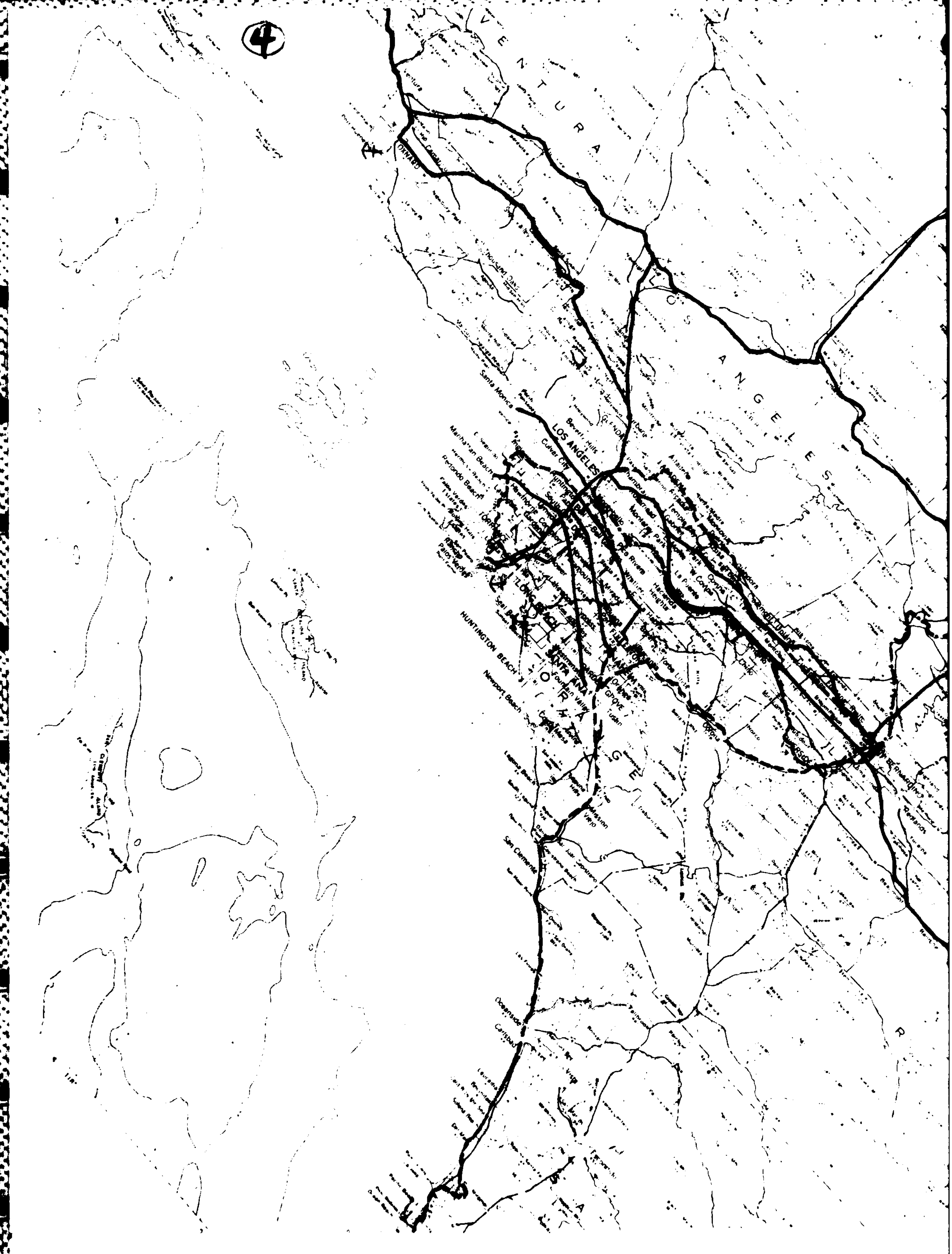
1

SAN LUIS OBISPO
SANTA BARBARA
San Luis Obispo
Santa Maria
Lompoc
Santa Barbara

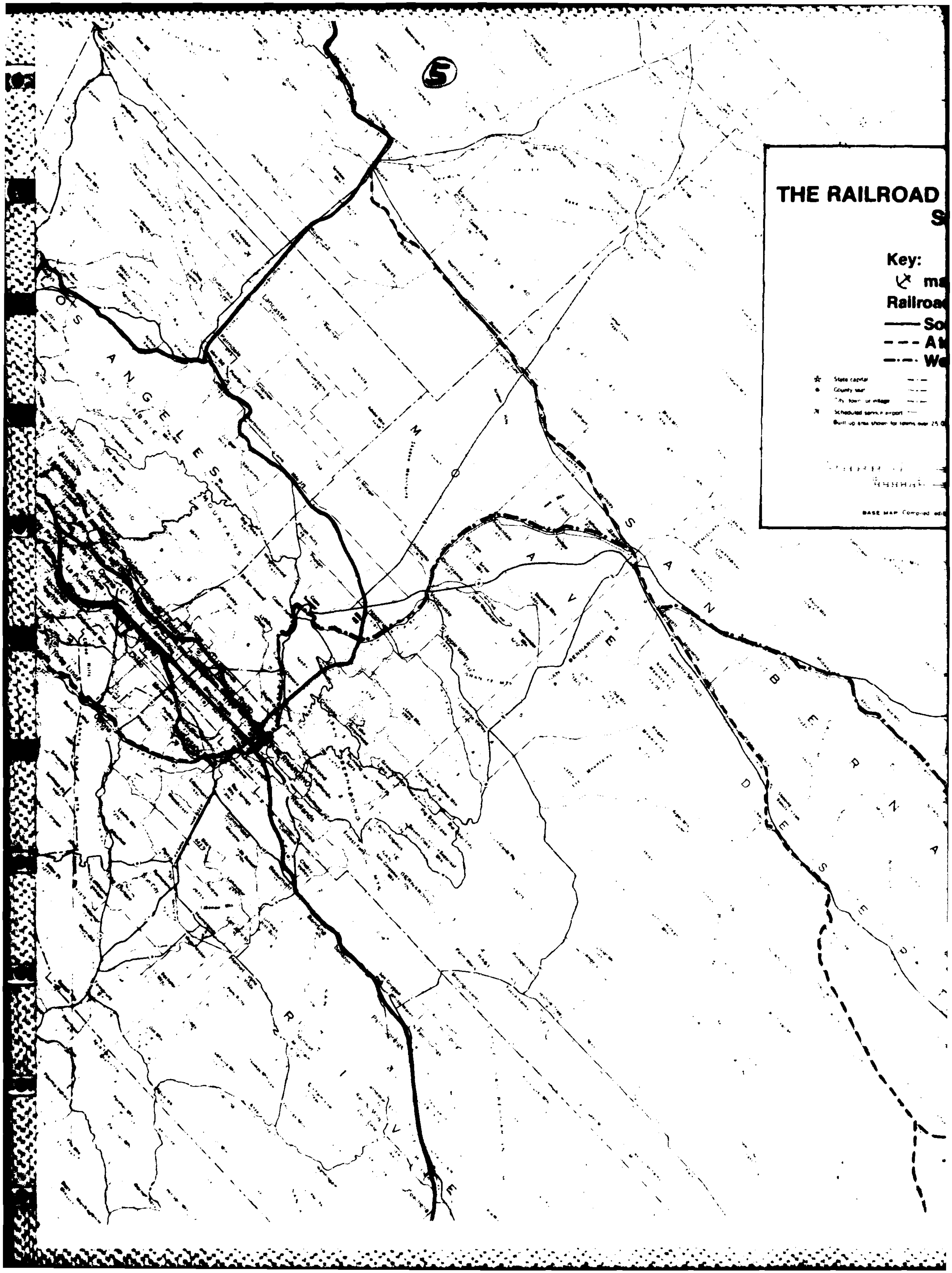

2
FRESNO
KINGS
TULARE


MONO
MADERA
FRESNO
NEVADA
3

4



VENTURA
LOS ANGELES
ORANGE
OXNARD
Santa Monica
Beverly Hills
Culver City
Manhattan Beach
Redondo Beach
LONG BEACH
SANTA ANA
HUNTINGTON BEACH
Newport Beach
San Clemente
Oceanside



5
THE RAILROAD
S
Key:
ma
Railroad
So
At
We
Lancaster
MOUNTAINS

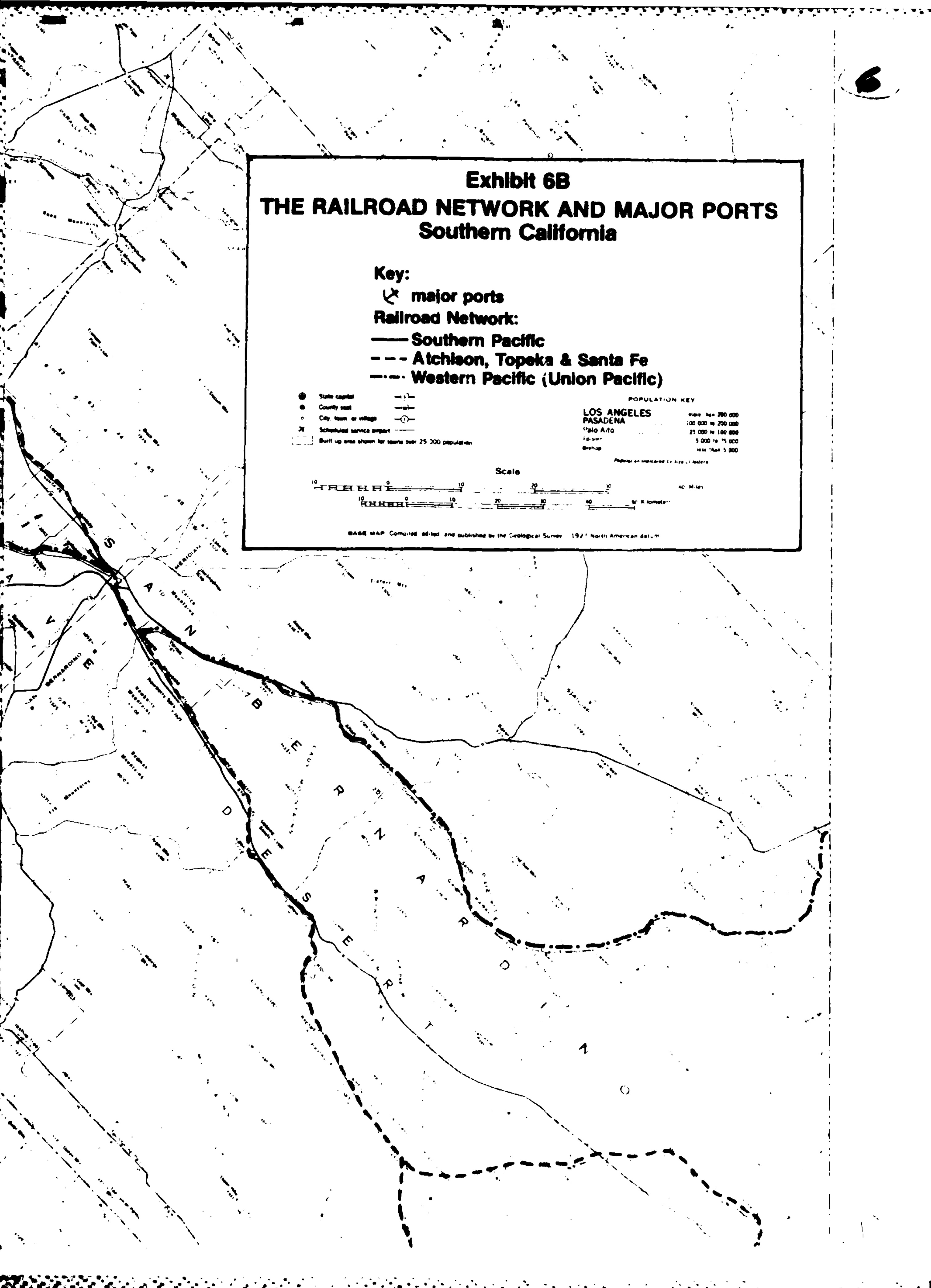
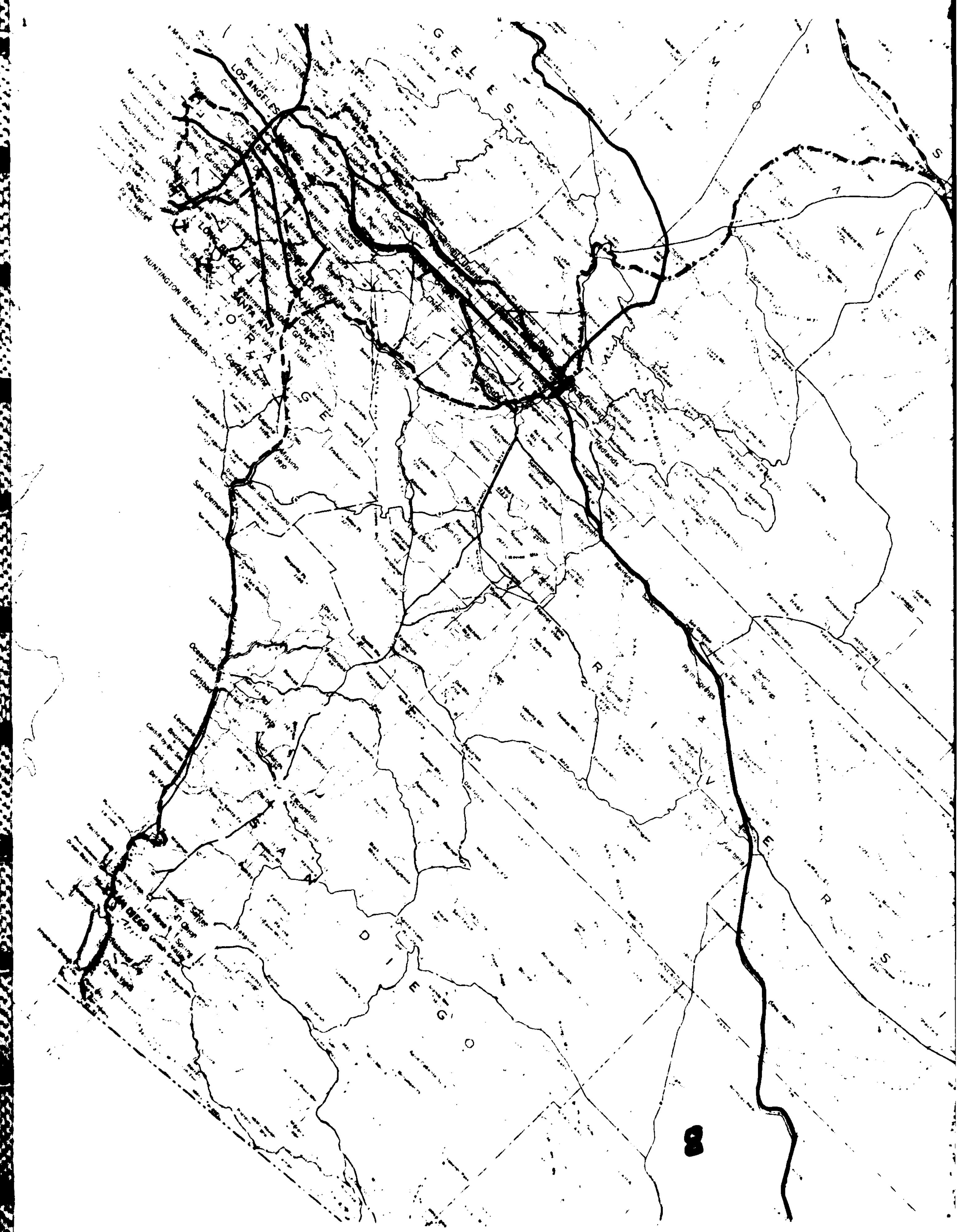
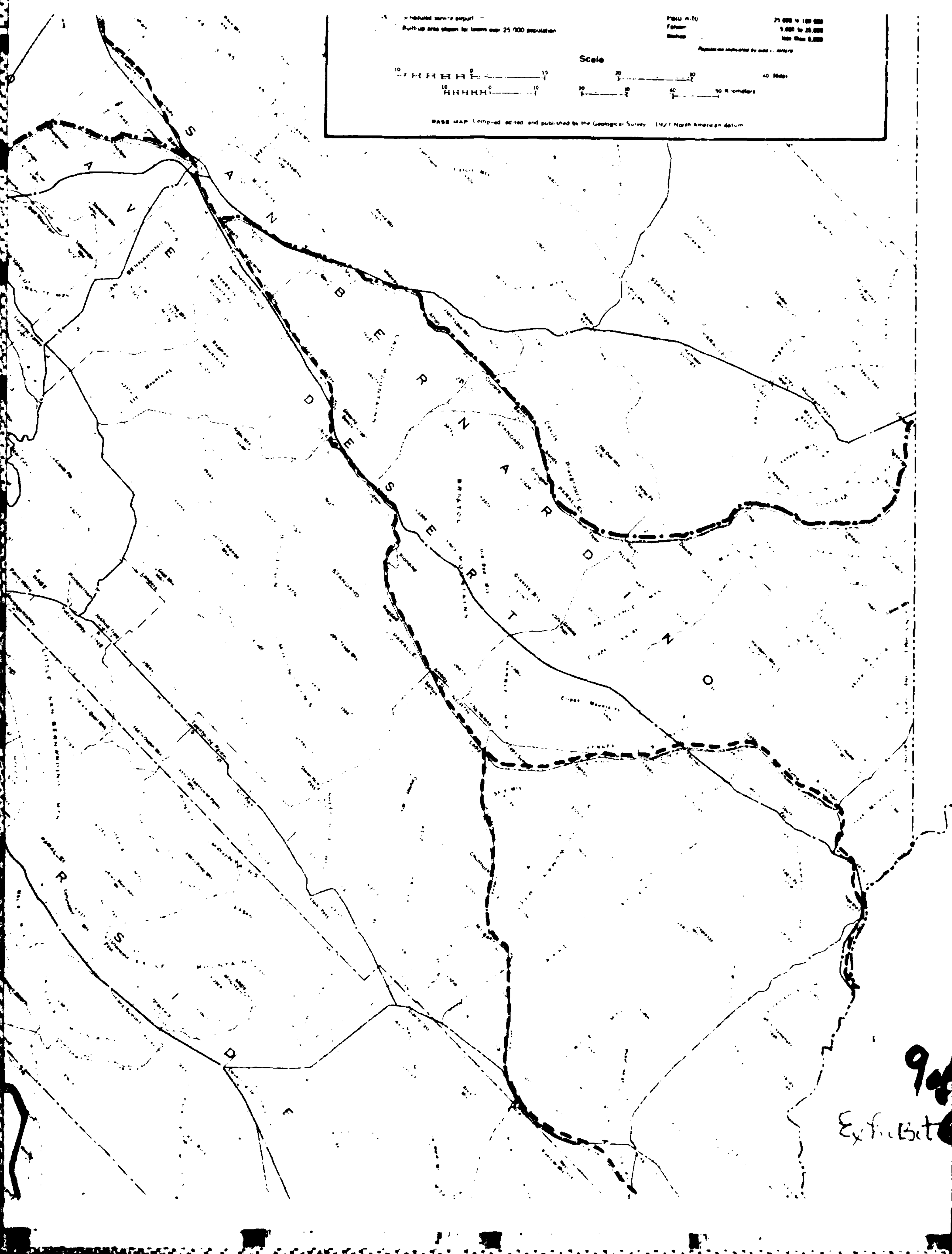


Exhibit 6B
THE RAILROAD NETWORK AND MAJOR PORTS
Southern California

LOS ANGELES
LONG BEACH
HUNTINGTON BEACH
SANTA ANA
Newport Beach
San Clemente
Oceanside
Carlsbad
SAN DIEGO
O R A N G E
S A N D I E G

7


LOS ANGELES
LONG BEACH
HUNTINGTON BEACH
SANTA ANA
Newport Beach
San Clemente
Oceanside
Escondido
Redlands
Palm Springs
SAN DIEGO
Chula Vista
O R A N G E
R I V E R S I D E
S A N D I E G O


Scheduled service airport
Built-up area shown for towns over 25,000 population
Palo Alto
25,000 to 100,000
5,000 to 25,000
less than 5,000
Scale
40 Miles
50 Kilometers
BASE MAP Compiled, edited, and published by the Geological Survey 1927 North American datum
SAN BERNARDINO
RIVERSIDE
STANDARD
PARALLEL
BRISTOL
Exhibit